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Description of Manganese Nodule Processing Activities for Environmental Studies

Volume I. Processing Systems Summary

August 1977

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National Oceanic and Atmospheric Administration
Office of Marine Minerals

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Description of Manganese Nodule Processing Activities for Environmental Studies

Volume I. Processing Systems Summary

August 1977

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National Oceanic and Atmospheric Administration
Office of Marine Minerals

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Office of Marine Minerals

ABSTRACT: This contract report was prepared for NOAA's Office of Marine Minerals to bring together technological information pertinent to the processing of manganese nodules mined from the sea floor and to help access the effects of manganese nodule processing activities on land and marine environments. It treats potential methods, operations, and requirements for processing and handling manganese nodules on land and at sea, including recovery of value metals, transport of manganese-nodule ore and process wastes, treatment and disposal of wastes, material and energy balances, and resource requirements. The report is available through the U.S. Department of Commerce's National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22151 (telephone: 703-557-4600), in three volumes:

Volume I. Processing Systems Summary
Volume II. Transportation and Waste Disposal Systems
Volume III. Processing Systems Technical Analyses

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EXECUTIVE SUMMARY

It is possible that a deep ocean mining industry based on the recovery and processing of manganese nodules will be developed in the United States during the next decade. Development of the industry will, in all likelihood, require some Federal actions which would be classified as "major Federal actions" under the National Environmental Policy Act. Thus, it is essential that the positive and negative impacts associated with development of the industry be assessed. The National Oceanic and Atmospheric Administration (NOAA) has undertaken a multi-phased program to assess the environmental and socio-economic impacts of the proposed industry. Before these assessments can be made, the relevant activities associated with the industry must be described. These include documentation and characterization of transportation, processing and waste disposal facilities which will be utilized. Specifically, the objective of the study described herein is to identify and describe in detail the production facilities that will most likely be required by a first generation nodule mining industry.

A number of factors determine the production levels and process technologies to be utilized in first generation plants. The principal constraints on production levels will be 1) availability of capital for plants recovering copper, nickel, and cobalt (three-metal) and 2) manganese market impact for plants recovering four metals. For three-metal plants, the total investment ceiling is assumed to be in the range of $500 million in 1976 dollars, equivalent to about three million dry short tons per year (dtpy) or 2.7 million dry metric tons (tonnes) per year (dmtpy). A four-metal plant has a higher potential return on investment than a three-metal plant, but the manganese production from a single 1.0 million dtpy or 0.9 million dmtpy plant would approach 30 percent of current U.S. consumption. Thus, market impact of a four-metal venture and capital requirements of a three-metal venture are expected to constrain production levels.

Based on the conclusions of several previous investigators and an objective review of the processing options that have been described in the literature, it is concluded that the state of technological development of extractive metallurgy at this time suggests that first generation plants may employ one or all of five process options. These are:

For three-metal plants
1) Reduction/ammonia leach
2) Cuprion/ammonia leach
3) High temperature sulfuric acid leach

For four-metal plants
4) Smelting to matte, following reduction roast, and conventional leach
5) Reduction/hydrochloric acid leach

The first three are variations of commercial laterite ore processing techniques. Much of the smelting technology is transferrable from laterite and sulfide ore processing. Only the hydrochloric acid route is totally new.

The basis for the description and characterization of processing plants presented in this report are detailed flow sheets and material and energy balances. The basic data needed to develop the flow sheets and material and energy balances were obtained from available scientific and patent literature. Since this literature is far from comprehensive, a good deal of engineering judgement, knowledge of the state-of-the-art and knowledge of analogous industrial processes were utilized in development of flow sheets and material and energy balances for each of the five processing techniques. The detailed flow sheets and the material and energy balances are provided in Volume III of this report.

The flow sheets and material and energy balances formed the basis for characterizing pertinent aspects of plants designed around each of the five processing techniques. Specifically, the following data were developed and are summarized for each of the processing techniques in Volume I.*

a) A brief, general summary description of the process.
b) A summary of plant inputs and outputs, including identification of major and pertinent minor constituents of waste streams. The general physical characteristics of important waste streams are also described.
c) Distribution of potentially toxic trace elements through the process and in all discharges.
d) A summary of plant support requirements, including power, fuels, manpower and land.
e) An analysis of potential accidental, off-site, releases of contaminants.
f) An analysis of the noise that would be generated by each plant.

The table titled Process Summaries summarizes the major process inputs and outputs for three-metal and for four-metal plants based on treatment processes determined to be most likely to be used by the industry.

Both three-metal and four-metal plants can be built to meet existing environmental standards. Liquid and solid wastes would probably be stored in containment structures as is common practice in the metals and chemical industries. For three-metal plants, the wastes stored in containment structures can be considered as a potential future source of manganese, or in essence a stockpile of manganese ore.

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*Volume II describes alternative transportation and waste disposal systems.

PROCESS SUMMARIES
(English Units)

Inputs	3-Metal Plant	4-Metal Plant
Nodules	12,500 tpd	3750 tpd
Coal	1,100 to 2,100 tpd	730 to 1,390 tpd
Water (consumed)	4.7 to 6.3 x 10^6 gpd	2.1 to 3.3 x 10^6 gpd
Land	180 to 200 acres	100 to 120 acres
Purchased Power	0 to 23.5 MW	70.3 to 94.5 MW
Work Force	500	300

Outputs		
Solid Wastes	8,600 to 12,500 tpd	1, 900 to 2,300 x 10^6 tpd
Liquid Wastes	2.75 to 3.4 x 10^6 gpd	0.61 to 0.67 x 10^6 gpd
Copper	92 to 97 tpd	26 to 29 tpd
Nickel	108 to 115 tpd	34 to 36 tpd
Cobalt	12 to 13 tpd	0.50 to 0.61 tpd
Manganese	0	630 to 760* tpd

*Ferromanganese

PROCESS SUMMARIES
(Metric Units)

Inputs	3-Metal Plant	4-Metal Plant
Nodules	11,400 tpd	3,400 mtpd
Coal	1,000 to 1,100 mtpd	660 to 1,300 mtpd
Water (consumed)	18 to 24 x 10^3 m^3/day	8 to 12.5 x 10^3 m^3/day
Land	72 to 80 hectares	40 to 48 hectares
Purchased Power	0 to 24 MW	70 to 95 MW
Work Force	500 persons	300 persons

Outputs		
Solids Wastes	7,800 to 11,400 mtpd	900 to 2,100 mtpd
Liquid Wastes	10 x 13 x 10^3 m^3/day	2.3 to 2.5 x 10^3 m^3/day
Copper	84 to 88 mtpd	24 to 26 mtpd
Nickel	98 to 105 mtpd	31 to 33 mtpd
Cobalt	11 to 12 mtpd	4.4 to 5.2 mtpd
Manganese	0	570 to 690* mtpd

*Ferromanganese

Gaseous emissions are not excessive nor particularly noxious since they are primarily combustion offgases. These emissions can be controlled utilizing existing technology.

Hazards associated with accidental spill or release of toxic materials stored at the plant site are very small. For example, the probability of damage resulting from accidental spills or releases at these plants is significantly less than that associated with spills from truck or rail accidents and such a plant would generally be constructed with a surrounding buffer zone. Noise levels at plant boundaries are not excessive, being similar to noise levels in a large, active office complex.

Treatment of wastes, to render them less toxic and amenable for certain types of disposal, was evaluated as a possible add-on to the processing plants. Since process plants, overall, look like conventional hydrometallurgical or pyrometallurgical plants in terms of operations, utilities, labor and size, waste treatment probably would not require developing new technology. Instead, existing operations could be adapted to treat wastes.

Three waste treatment alternatives are technically feasible. These include:

1) Precipitation or fixation of soluble toxic elements with direct discharge of treated wastes into containment structures.
2) Precipitation of soluble toxic elements followed by washing of solid wastes to remove soluble innocuous and toxic elements for separate treatment or control.
3) Precipitation of toxic elements followed by washing and drying of solid wastes.

The degree of waste treatment required would depend on the waste disposal method. That is, a lined tailings pond might require little or no treatment. In contrast, disposal in a land fill would require washing and drying (alternative 3) at high cost.

An evaluation of the possibility of at-sea processing was made. There are three general options:

1) physical beneficiation
2) partial processing
3) full at-sea treatment to finished products

The first of these is not feasible because of the mineralogy of the nodules. The third option, full at-sea processing, would require development of new technology in electrowinning and probably in liquid ion exchange. Therefore, the option is not likely in first generation plants. The second option, partial processing at sea, is possible for all of the processes evaluated except smelting. However, the economic incentives are unclear because some land processing is still required and the relative costs of transportation, waste disposal and increased process complexity are unknown. Of the five processes evaluated, only smelting is not a candidate for partial at-sea processing.

The ammonia (including Cuprion) and sulfuric acid based plants for partial processing at-sea can be accommodated on a vessel of reasonable size, about 20,000 dwt. The requirement to store materials, supplies and products increases size requirement to about 100,000 dwt if an impure metal mixture is produced and to 200,000 dwt if a pregnant liquor is produced. There is no incentive to produce a pregnant liquor because of increased transportation and sea plant size requirements.

Production of an impure metal precipitate at sea with subsequent purification and finished metal production at a land plant appears technically feasible and would reduce land requirements for waste disposal, if wastes generated at sea can be disposed of at sea. This at-sea disposal is necessary for the system to be economically viable. Transported tonnages would decrease, but hazardous materials would have to be shipped to the sea plant. The net impacts on total capital and operating costs are not clear.

1.0 INTRODUCTION

1.1 DEEP OCEAN MINING IN PERSPECTIVE

Manganese nodules are potato-shaped concretions found on the deep ocean floor in many parts of the world. Although somewhat variable in composition, these nodules may become an important source of nickel, copper, cobalt, and manganese. Manganese nodules can be regarded as a relatively high grade nickel-copper-cobalt oxide ore since nickel, copper and cobalt are the most valuable recoverable constituents of manganese nodules.

While deposits of manganese nodules occur in every major ocean, those in the near-equatorial North Pacific are of greatest interest at present because of the greater nodule density in many deposits and their higher than average concentrations of metal values. High concentrations of nodules have been observed over many thousands of square miles of ocean floor and have been estimated to average 10 kg/m^2 (2 lb/ft^2) wet weight in mineable areas. This is therefore an enormous potential reserve.

The deposits of greatest commercial interest lie in a belt south of the Hawaiian Islands and north of the Equator and extend almost from Mexico to 180°W (see Figure 1.1). Typically, these deposits lie at depths between 4,000 and 6,000 meters (13,100 and 19,700 feet).

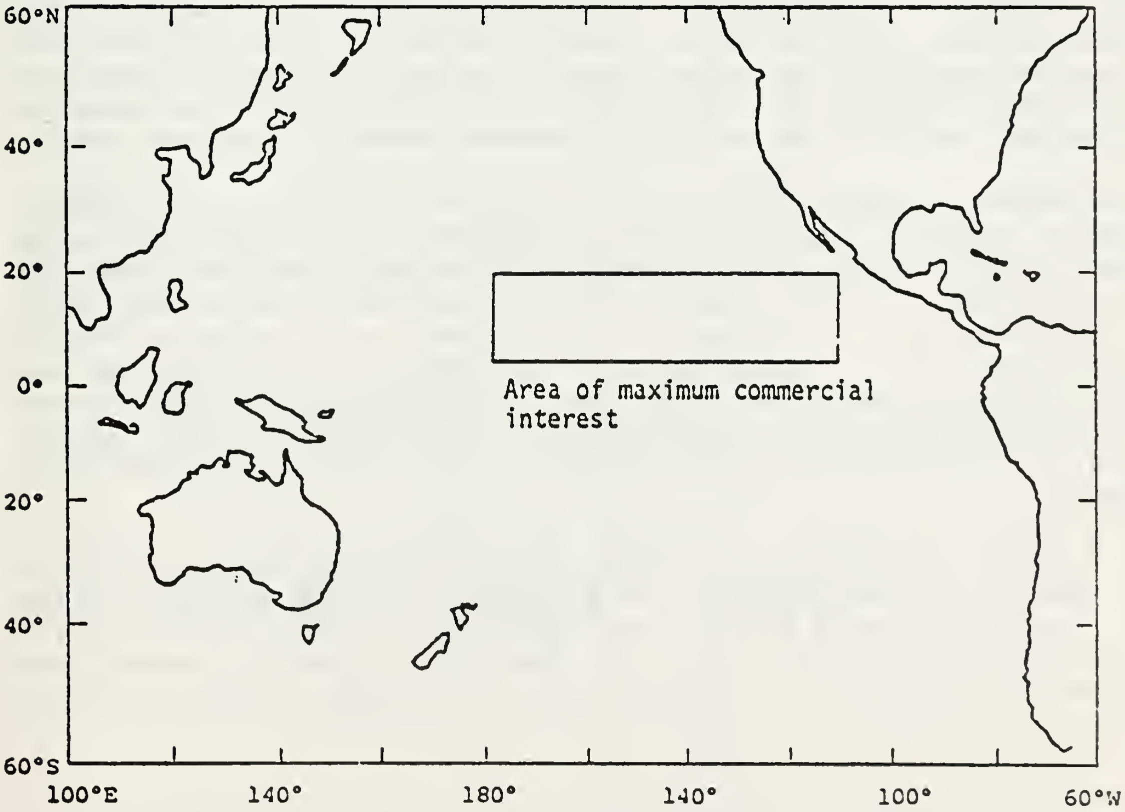

FIGURE 1.1 NODULE MINING AREA OF MAXIMUM COMMERCIAL INTEREST

Although the technologies required to locate, mine and process manganese nodules have not yet been demonstrated on a commercial scale, no technological problems are apparent which would preclude development of this resource, given a favorable economic and political climate. Accelerated engineering and development activities over the past decade, with their attendant considerable investment, suggest that initiation of large scale mining could occur as soon as the early 1980s. In addition to possible economic incentives, development of a manganese nodule mining industry in the United States has possible strategic value. The United States is not presently self-sufficient in manganese, nickel, and cobalt. Almost all of our supplies of these metals must be imported from foreign countries; hence our supply and the price we must pay is largely controlled by other nations.

Because of economic and strategic incentives and our leadership in the required technology, the United States will probably be the leader in the development of the manganese nodule deposits found in deep ocean basins. Because of proximity to our shores and high concentration of metal values, the deposits south of Hawaii appear to be the most likely targets, at least for first generation operations. In general, an ocean mining operation will consist of mining vessels, a fleet of carriers which will transport nodules (ore) to a port facility and an on-shore processing plant. There is a possibility that at-sea (shipboard) processing or partial processing may be feasible in the future. However, technical and other problems with at-sea processing will probably lead to use of onshore plants in first generation systems. Since initial nodule mining operations will probably be centered in the belt south of the Hawaiian Islands, the West Coast, Hawaii, Alaska, or possibly the Gulf Coast may be considered by industry for the siting of port facilities and onshore processing plants. The industry's decisions will be based on total system economics and regulatory considerations in potential areas.

In summary, there appear to be sufficient economic and strategic incentives to develop an ocean mining industry in the United States in the near future. Thus, it is essential to examine both the potential positive and negative environmental and socio-economic effects associated with development of this industry if development is to maximize overall benefit to society. A comprehensive assessment of both positive and negative factors constitutes vital input to the decision making process inherent in establishing a new industry. This assessment will not be easy, since the industry will utilize, in part, new methods and technologies.

A relatively complete knowledge of the methods and technologies to be used by the industry must be available to allow analysis of impacts. Opportunities to draw on past experience to develop the required data base are very limited. Thus, the required data must be gleaned from a variety of sources and synthesized into a reasonable characterization of the new industry, recognizing that certain inaccuracies are probable in this approach. A large degree of engineering judgment is required to characterize this potential new industry because of the scarcity of published data. This report identifies and describes the processing facilities which will be needed to recover value metals from manganese nodules and provides the information needed for impact analyses.

1.2 PURPOSE OF NOAA PROGRAM

It is likely that one or more Federal actions will be associated with the development of a deep ocean mining industry in the United States and it would be considered a "major Federal action" under the National Environmental Policy Act (NEPA). Thus, it is likely that the Federal Government will be required to prepare one or more environmental impact statements before such an industry can develop. Review of published information dealing with the broad topic of manganese nodules reveals that little or no work has been done, or at least divulged to the general public, on the potential environmental impacts associated with mining, transportation, and processing of manganese nodules. Since this may well become a major industry, both positive and negative environmental effects may be significant. Failure to understand, anticipate, and control or mitigate potential adverse impacts could also lead to delays and add to the total cost of development of the industry. Such work can also aid industry by permitting the design of operations which are environmentally compatible to the maximum practical extent.

As a result, the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) has undertaken two studies to assess the potential impacts of the new industry. The Deep Ocean Mining Environmental Studies (DOMES) Project, already underway, is designed to assess the potential environmental effects of at-sea nodule mining operations in the central Pacific nodule belt and to develop information for appropriate environmental safeguards. In a complementary project the NOAA Office of Marine Minerals has initiated a three-phased program to assess the environmental and socioeconomic impacts of other activities associated with development of the industry, specifically, ore (nodule) transportation, processing of nodules and disposal of process wastes.

The objective of Phase I of the NOAA Program is to describe and characterize the relevant activities associated with at-sea and land transportation, processing, and waste disposal in a manner suitable for use in subsequent environmental and socioeconomic impact studies. The Phase I work was performed under two separate, competitively awarded contracts. The work on processing systems was designated "Phase IA" and the work on transportation and waste disposal was designated "Phase IB". Contract work on Phase IA begin during July 1976.

1.3 PURPOSE OF THIS STUDY

The Phase IA study was designed to identify and characterize on-shore and off-shore processing methods most likely to be used by the industry. The characterization required developing material and energy balances; identifying wastes produced, resources consumed and noise generated; describing waste treatment alternatives and describing at-sea processing alternatives to land plants. These items are essential to subsequent phases of the NOAA Program wherein this information will be used to assess the potential impacts related to processing and related activities of the industry. The Phase IA work is summarized in this volume. The detailed analyses upon which this summary is based are provided in Volume III.

The Phase IB study, which is summarized in Volume II of this report, characterizes likely sea and onshore transportation systems and alternative waste disposal methods. The Phase I study and the DOMES Program are designed to supply the data base needed to assess environmental impacts of mining, transporting, processing and disposing of wastes associated with the future manganese nodule mining industry.

It should be noted that the Phase I work is designed to serve as an input for subsequent impact studies and not to assess potential impacts. Care must also be taken in the interpretation of the Phase I results, since it is unusual to develop this type of information at this stage of industrial development (i.e. without prototypes in operation).

1.4 SCOPE OF STUDY

The scope of this study included the following:

a. identification of possible nodule treatment processes;

b. development of rationale for selection of most likely process routes;

*c. development of rationale for selecting production rates for 3-metal and 4-metal plants;

d. development of detailed process flow sheets and process materials and energy balances for the most likely processes;

e. description and quantification of 1) physical and chemical characteristics of plant wastes 2) distribution of potentially toxic materials 3) type and frequency of accidental releases of potentially dangerous materials 4) plant water, power, land and manpower requirements 5) noise produced by plants and 6) waste treatment methods;

f. at-sea processing alternatives

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*"Three metal processing plants" are those which will recover only copper, nickel and cobalt. "Four metal plants" recover these metals and manganese.

The scope of work included assessment of only existing technology and is based on review of available technical literature and patents. No attempt was made to research and develop new technology. However, the most up-to-date process technology was used as a basis for selecting and describing the likely nodule processes. In cases such as waste treatment, where essentially no literature is available, only techniques which are in use, or which are state-of-art methods recognized as viable were described.

In order to help assess the realism and relevancy of the work, NOAA requested industry, environmental interest groups, and interested agencies (e.g. the Department of the Interior's Bureau of Mines and the U.S. Environmental Protection Agency) to review the work and to constructively comment on its results. This was done through a series of public briefings which were attended by industry, government, and outside processing experts as well as by representatives of environmental interest groups and the public.

Completing this study required that very detailed and complete process flow sheets and material and energy balances be developed for each process. These are summarized in this Volume. The detailed flow sheets and material and energy balances are presented in Volume III of this report. An annotated bibliography is also presented in Volume III. Certain technical terms, which may not be familiar to some readers, are defined in Section 10.

2.0 PROCESSING TECHNIQUES AND PRODUCTION LEVELS

2.1 IDENTIFICATION OF LIKELY PROCESS ROUTES

2.1.1 Method and Rationale

The major objective of the Phase IA study was to identify those treatment schemes or processes considered "most likely" to be used by the industry for first generation nodule processing plants and to describe these in a manner suitable for use in subsequent environmental and socioeconomic impact studies. Identification of process routes was made through a rather comprehensive review of pertinent scientific and patent literature. This served as a guide to the process routes being developed by major companies and by research institutions active in this field. The literature review yielded information on many processes which showed at least some promise of being suitable for treating manganese nodules. It is evident from the literature that the bulk of research work presently being done by the major consortia actively interested in deep ocean mining was limited to relatively few processes. In general, each consortium is concentrating on development of a specific process. Despite this, no process was rejected from consideration in this study unless it could be reasonably demonstrated that some inherent characteristic rendered it highly impractical from either a technical or economic standpoint. Analysis of the availability and/or cost of required chemical reagents and other process materials served to eliminate certain treatment routes from consideration early in the selection process.

Selection of a process scheme by a developer will be based on evaluation of the many parameters bearing on technical feasibility and economics. No "optimum" processing technology exists. Rather, special circumstances and external variables may favor the adoption of one or another process route to suit the needs of each developer. Thus, no attempt is made to rank potential processes in terms of either technical or economic advantage. Similarly no analysis or ranking of the environmental advantages and disadvantages of the processes was made.

Examples of external variables bearing on selection of a process route by a developer include: 1) assurance of continual access to a reliable supply of nodules of a given grade and range of physical and chemical characteristics; 2) need for a dependable supply of process chemicals and reagents; 3) disposal of process wastes; and 4) availability of power, water and other raw materials; and 5) local environmental protection and regulatory considerations.

2.1.2 Classification of Processing Schemes

A critical step in most processes is the reduction of the manganese oxidation state to break down the nodule matrix and liberate the contained value metals. For the purposes of this study, we have chosen to classify processes either as a smelting operation or according to the leaching solution (lixiviant) used to reduce and/or leach the nodules in hydrometallurgical processes. Lixiviants used in hydrometallurgical processes can be classified into three major types; those producing acid sulfate solutions, those producing chloride (halide) solutions and those producing ammoniacal solutions. The types of extractive metallurgical processes evaluated in this study are presented in Table 2.1.

TABLE 2.1

CLASSIFICATION OF EXTRACTIVE METALLURGICAL PROCESS SYSTEMS

System Type	Process Descriptions
Sulfate Systems	*High Temperature Sulfuric Acid Leach *Smelting Sulfuric Acid Reduction Leach Reduction Roast/Sulfuric Acid Leach Sulfation Roast
Ammoniacal Systems	*Reduction/Ammonia Leach *Cuprion/Ammonia Leach High Temperature Ammonia Leach
Chloride Systems	*Hydrochloric Acid Reduction Leach Hydrogen Chloride Reduction Roast/ Acid Leach Segregation Roast Molten Salt Chloridation

*Process Systems chosen as likely to be used in first generation plants

Of the major hydrometallurgical and smelting routes identified in this section, only the HCl process requires recovery of a manganese product. The reduction/ammonia leach process disrupts the nodule manganese matrix, but the resulting manganese is rejected as a carbonate or an oxide in the plant waste stream. The pyrometallurgical approach yields a manganese-rich slag from which ferromanganese can be recovered. Alternatively, the slag may be easily stockpiled for future recovery of manganese or can be considered waste.

All of the process options reject iron, a major constituent of manganese nodules, so that one is left essentially with the problem of separating and recovering the three principal value metals, i.e., nickel, copper and cobalt. All process schemes result in solubilization of the three principal value metals so that separation and recovery in all processes are effected hydrometallurgically.

2.1.3 Selection of Most Likely Process Routes

Several recent papers have summarized the processing routes suitable for treating manganese nodules (Agarwal et al, 1974, 1976a, 1976b; Barbier, 1973; Cardwell, 1971; Faugeras, 1971; and Tinsley, 1975). All of these reviews conclude, as we have, that the most likely processing routes involve smelting and/or hydrometallurgical processes. The rationale utilized in arriving at conclusions regarding the "most likely" processing methods are summarized in the following paragraphs.

The grade of available ore (nodules) reserves will play a major role in selecting the process and production level for a given processing plant, but, within limits, it is to be expected that a favorable ore can be made available for each process option. Subsequently, the key decision from a processing point of view is whether or not to recover manganese as a primary process option or simply to build a so-called three-metals plant to recover copper, nickel, and cobalt. The economic and processing impact of either decision is discussed in the following paragraphs.

Excluding manganese, the value of nodules is primarily in the 1.0 to 1.5 percent nickel content, with copper and cobalt playing significant but secondary roles. As such, nodules must compete with lateritic ores found on land which typically contain about 1.5 percent nickel and 0.1 percent cobalt. With recoveries of 75 percent for nickel and 50 percent for cobalt, the returns from this ore would be of the order of $45-50/tonnes (or ton within the accuracy of this analysis) above mining costs. For nodules, however, mining and transportation costs are likely to be higher by about $20/tonnes so that returns will have to be approximately $65-70/tonnes to compete with laterites. For a high-value 2.9 percent nickel/copper/cobalt nodule ore, recoveries of 70-75 percent of all metals would be required. Even at $10/tonnes delivered nodules cost, recoveries of over 70 percent are required, and higher recoveries are obviously desirable to offset the higher risks inherent in the development of new technology.

Energy costs and capital charges are key components in the costs of processing lateritic ores. It is also likely that they will both be high for nodules processing. Thus other operating costs, particularly lixiviant consumption and loss, must be carefully controlled to obtain favorable economics. The process must be either essentially closed with respect to lixiviant use through effective regeneration/recycle or a special situation must exist with respect to the economics of supply and disposal of make-up and spent lixiviant.

Since low temperature sulfuric acid leach processes show rather low metal recoveries even at long leach times, they are not likely candidates for economic processing routes. The same consideration applies to segregation roasting. High temperature sulfuric acid leaches, however, show good to excellent metals recoveries. While sulfuric acid consumption may be as high as 0.3 kg/kg of nodules, it is a readily available and relatively inexpensive lixiviant. Furthermore, since much of this technology is practiced in laterites processing at Moa Bay, Cuba, an element of risk is removed. These factors lead to the conclusion that high temperature sulfuric acid leaching is a likely processing alternative.

Reduction leach processes based on ammonia/ammonium carbonate as a lixiviant are also well known in laterites processing. Furthermore, they show good to excellent metals recoveries and are highly selective. A newly developed hydrometallurgical, low temperature reduction/ammonia leach process is particularly interesting in that it combines operations and should save energy, offsetting the energy requirements involved in lixiviant recovery and recycle.

This process, the Cuprion/ammonia leach process is very similar to the reduction/ammonia leach process and has the same advantages. As such it is also a likely processing alternative.

In these terms, then, high temperature sulfuric acid and the two ammonia leach processes must be considered as three hydrometallurgical processing alternatives for a three-metal plant.

Basically the same considerations will apply in selecting probable process routes for plants which recover manganese as well as copper, nickel and cobalt. In this case, however, there is no analogous current practice that might guide technology development and evaluation.

Smelting processes are candidates for routes involving manganese recovery because their inherently high energy requirements demand high revenues per unit of throughput. Since technology exists for metals recovery from copper/nickel sulfide mattes, an element of risk is removed. Also, it is known that recovery of those metals can be high. If additional revenues from manganese production are required, then a ferromanganese product can also be produced from the slag. While significant questions remain as to the purity of the manganese product and the overall process economics, the smelting approach cannot, a priori, be rejected from consideration.

Both sulfating roast and sulfur dioxide reduction leach processes are candidates for routes to manganese recovery since solubilization of all metals is high. However, problems arise in trying to construct integrated processes based on these approaches. As the metals are recovered from solution, the sulfate anion is converted to sulfuric acid. It is not likely that the acid, in turn, could be economically reduced to sulfur dioxide for recycle. It would be purged from the system as a relatively low strength, quite impure acid stream which will even be difficult to upgrade to industrial grade acid for sale for by-product credits. Disposal would likely require neutralization, with large consumptions of lime and the generation of large waste streams. Thus, sulfating systems are not likely to be viable process alternatives. The same considerations apply to schemes in which the lixiviant is ammonium sulfate.

It is conceivable that these same objections could be raised with respect to systems employing chloride reduction roast/leach schemes, in spite of the acknowledged high recoveries of all the metals. In this case, however, the reduction reaction liberates a relatively pure and valuable byproduct (chlorine), and the lixiviant (chloride ion) can be oxidized during metal recovery to produce additional chlorine or recovered as hydrogen chloride for recycle. It may then be possible, as a special circumstance, to arrange buy-back arrangements in hydrogen chloride and chlorine with a manufacturer of chlorinated hydrocarbons if the nodule processing plant is adjacent to a chlor-alkali or similar complex, even though tonnages involved would be quite large.

The alternative is to buy large amounts of hydrocarbons or hydrogen directly to regenerate hydrogen chloride. While this would involve known technology, it would probably not enhance process economics. Nevertheless, objections which are major for the sulfating processes can be overcome and chloride based processes would be considered where manganese production is a process objective.

In summary, we conclude that the most likely process options for the recovery of metal values from nodules are:

3-Metal Plants
1) high temperature sulfuric acid leach;
2) reduction leach using ammonia/ammonium carbonate; and
3) cuprion/ammonia leach

4-Metal Plants
1) smelting; and
2) reduction/hydrochloric acid leach

2.2 ESTIMATES OF PRODUCTION LEVELS

A prerequisite of this study was to develop estimates of the probable scale of operation of first generation nodule processing plants. The criteria for estimating the "most likely" scale of operation is one which provides an acceptable return on total investment within the constraints imposed by the developer's ability to raise the required capital. Estimation of the probable scale of first generation mining and processing operations is required to establish probable processing plant nodule throughput rates so that the process material and energy balances could be quantified.

During the past decade, several economic assessments have appeared in the rapidly growing literature on manganese nodule mining and processing. While there are wide variations among the estimates, there is general agreement that development of the world deposits of manganese nodules offers potential returns sufficient to offset the significant risk inherent in an ocean mining venture and development of new technology.

2.2.1 Parameters Affecting Process Rates

Parameters bearing on the economics of nodule mining and processing rates include:

1) extent of ore reserves
2) ore grade
3) mining efficiency and rate
4) process metal recovery efficiency
5) capital and operating costs
6) metal markets and prices
7) legal and political constraints

The implications of these factors are briefly summarized in subsequent paragraphs. They are discussed in detail in Volume III.

Ore reserves represented by manganese nodules appear enormous and to occur in sufficiently concentrated deposits to support orderly mining from well defined mining sites. Combined nickel-copper-cobalt grades of 2.5 percent offer revenues superior to most available laterite nickel deposits, with manganese a potential source of additional income. That is, sufficient ore reserves of a profitable grade are probably available to support any reasonable mining rate.

Development of an adequate mining system represents a formidable task, since selectively lifting the manganese nodules some three miles from the deep ocean floor to its surface represents entirely new technology. Two main types of mining system are being developed by industry to mine deep ocean manganese nodules: hydraulic and mechanical. At present, hydraulic systems seem to be favored by U.S. industry over the mechanical system. Both types of system have been tested on a pilot scale, with additional pilot scale as well as prototype testing scheduled during the next few years.

Hydraulic mining systems are designed to recover nodules by creating an upward flow of seawater and nodules from a collector on the seafloor, through a pipe to a surface mining ship. There are two methods which can be used to create the upward flow. The first is use of submerged pumps. The second method involves the injection of compressed air (this is also referred to an "air-lift") at various points in the pipe. The collector, which removes the nodules from the seafloor, rejects sediments and passes the nodules to the mouth of the pipe, may be either towed or self-propelled.

The mechanical system under development, or Continuous Line Bucket (CLB) system, consists of a series of buckets attached to a continuous line that will travel from one mining ship to the seafloor, along the bottom up to a second mining ship and over to the first ship. The cycle is then repeated. As the line travels, the buckets will descend, traverse the seafloor to collect nodules, and then ascend to the ships where they will be unloaded and lowered again. The original method, which utilizes a single ship, is also still under development but the two-ship system has received more industrial attention in recent years.

Alternative metallurgical processes for treating the mined nodules are discussed elsewhere in this report. While processing may be pyrometallurgical or hydrometallurgical, there is no reason to believe, at this point, that the economics of one or another route are inherently favored. A key factor for selecting the production level, however, would be the decision on recovery of manganese.

The major factors affecting likely production rates are plant capital and operating costs and the effect of economies of scale. At a scale of one million dry metric tons (tonnes) per year (1.1 million dtpy) capital cost estimates range roughly from $175 to $250 million. At three million dmtpy (3.3 million dtpy) estimates vary from $400 to nearly $800 million. Operating cost estimates vary even more widely. At one million dmtpy (1.1 million dtpy) the average operating cost estimate is about $70 per dry tonnes while at three million dmtpy, the average decreases to about $45 per dry tonnes. These figures are in terms of 1976 dollars.

The metals production for a four-metal plant would be about 10 times the metals production of a three-metal plant with the same nodule input. The metals recovery portion of the plant, a small portion of the total cost of the plant, and the utilities would increase proportionately to the increased metal production rate, so it is estimated that four-metal plant operating costs would be about double the operating costs of a three-metal plant of the same nodule input.

Most investigators conclude from reviews of metal market data projected into the next decade that nickel and copper prices are subject to upward pressures that should continue largely unabated despite the availability of nodule production. While cobalt prices may fall, they would not significantly alter nodule economics. The price and market situations for manganese could be greatly affected by manganese production from nodules since a single three million mtpy (3.3 million tpy) plant would produce approximately 90 percent of the U.S. consumption.

2.2.2 Potential Revenues and Profits

The potential profitability of nodule operations would be determined by the capital and operating costs of the venture at a given scale of operations, the magnitude of which has already been described. Revenues, then, depend on metal prices and ore grades.

The metal content of nodule ores is highly variable, and while average grades over a 20 year mine life might not exceed 2.5 percent for copper/nickel/cobalt, selective initial mining could produce 3.0 percent ores or higher. Table 2.2 indicates assumed high and low ranges in grades of nodule ores, coupled with forecast prices and recovery efficiencies to determine net revenues per ton of ore for a three-metal plant. The initial boost in revenues could increase considerably the discounted cash flow of a nodule processing investment. The data in Table 2.2 shows that a three-metal plant is predominantly a nickel plant from the standpoint of revenues. In a four-metal plant the manganese recovery more than doubles the total revenues.

Table 2.3 summarizes the overall financial status of three-metal nodule operations ranging from one to three million dmtpy (1.1 to 3.3 million dtpy) in scale. Both high range and low range revenues are presented for comparison.

TABLE 2.3

POTENTIAL PROFITS OF A THREE-METAL
NODULE PROCESSING OPERATION
(million 1976 $)

	Scale of Operation million dmtpy (million dtpy)				
	1 (1.1)	2 (2.2)		3 (3.3)	
High Range		a	b	a	b
Total Investment	276	415	388	521	488
Revenue	106	212	212	318	318
Ore Cost	28	56	44	71	59
Process Cost	43	78	78	106	106
Margin	35	78	90	141	153
After Tax Profit	18	39	45	72	77
ROI	6.5%	9.4%	11.6%	13.8%	15.8%
Low Range					
Revenue	91	182	182	273	273
Margin	20	48	60	96	108
After Tax Profit	10	24	30	48	54
ROI	3.6%	5.8%	7.7%	9.2%	11.1%

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[a] two-ship mining operation

[b] one-ship mining operation

Simple return-on-investment (ROI) calculations reveal that a three-metal operation becomes attractive only at a 2-3 million dmtpy (2.2 to

TABLE 2.2

NODULE OPERATION REVENUES

						Net Value			
			Price**			High Range		Low Range	
Mineral	High Range Grade (%)*	Low Range Grade (%)*	(per kg)	(per lb)	Process Efficiency	per ton	per tonnes	per ton	per tonnes
Nickel	1.5	1.3	$5.55	$2.50	90%	$ 67	$ 74	$ 58	$ 64
Copper	1.3	1.1	$1.87	$0.85	90%	$ 20	$ 22	$ 17	$ 19
Cobalt	0.25	0.2	$6.62	$3.00	60%	$ 9	$ 10	$ 7	$ 8
					Three-Metal Total	$ 96	$106	$ 82	$ 91
Manganese	25.0	25.0	$0.55	$0.25	90%	$112	$124	$112	$124
					Four-Metal Total	$208	$230	$194	$215

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*Mineral grade based on dry nodule weight.

**Assumed future prices based on common forecasts.

3.3 million dtpy). Short term simple returns in the range of 10-15 percent, when supplemented by significant depreciation, imply an adequate discounted cash flow for such investments. The long-term average ROI's suggest that 3 million dmtpy (3.3 million dtpy) may be the cutoff point below which investments will not be made. These calculations also assume that no depletion allowance will be taken.

The same estimates for four-metal operations are shown in Table 2.4. The simple returns are quite adequate at a one million dmtpy (1.1 million dtpy) level and marginal at 0.5 million dmtpy (0.55 million dtpy). Clearly, however, the success of a four-metal operation will depend heavily on stable manganese prices and successful market penetration.

TABLE 2.4

POTENTIAL PROFITS OF A FOUR-METAL
NODULE PROCESSING OPERATION
(million 1976 $)

	Scale of Operation million dmtpy (million dtpy)	
High Range	0.5 (0.55)	1.0 (1.1)
Total Investment	287	406
Revenue	115	230
Ore Cost	19	28
Process Cost	45	83
Margin	51	119
After Tax Profit	26	60
ROI	9.1%	14.8%
Low Range		
Revenue	108	215
Margin	44	104
After Tax Profit	22	52
ROI	7.7%	12.8%

These levels of profitability might be viewed as barely adequate to justify the assumption of the risks involved. The trend in new land-based mines (particularly nickel), however, is toward high infrastructure requirements since these deposits are usually located in remote areas. This greatly inflates capital investment needs. Recent reports of land-based nickel investments suggest a capital investment of $13-$18 per kilogam ($6-$8 per pound) of nickel equivalent (Wright, 1976). Nodule plant capital costs of roughly $11 per kilogram ($5 per pound) nickel equivalent in a three-metal operation compare quite favorably. Operating costs per pound appear to be similar for new land-based and for ocean mining operations. Further, the intangible benefits of a domestic processing plant versus heavy investment located in politically unstable developing countries should not be ignored. Nevertheless, no major nodule operations are likely to be initiated until the Law of the Sea Treaty negotiations are completed or the U.S. enacts interim domestic legislation in the absence of a treaty.

2.2.3 Conclusions

Because of capital limitations, the first three-metal nodule operations are likely to be sized at about 3 million dmtpy (or dtpy, within the accuracy of these estimates). This scale offers adequate potential returns and could break even despite major unplanned cost increases. Smaller-sized operations would have marginal profit potentials at best. On this basis, initial commercial operations less than 2 million dmtpy make little economic sense.

Four-metal nodule operations would be much smaller, probably in the range of about 0.5 to 1.0 million dmtpy. Because of manganese revenues, these sizes offer potential profits in an acceptable range. However, capital requirements per ton of capacity are significantly higher than those of a three-metal operation and hence market impact uncertainties are critical. This argues for the smallest possible investment. It should be stressed, however, that cost estimates for the four-metal operation are no more than rough approximations because there are no comparable operations in existence at the present time.

3.0 BASIC STUDY ASSUMPTIONS AND SOURCES OF INFORMATION

3.1 INTRODUCTION

The fundamental step in describing manganese nodule treatment plants based on the processes identified in Chapter 2.0 is development of process flow sheets and process material and energy balances. Once these data are developed for each process, a description and characterization of the factors needed to assess the probable impacts from each type of plant can readily be developed.

In this chapter the basic study assumptions and sources of information which are fundamental to the process descriptions are described. In Chapters 4.0 through 8.0, the five "most likely" processes are described.

Published technical literature and patents provided much of the data needed to develop the basic flow-sheets and material and energy balances. The literature was reviewed in some detail to glean any information which might be available on each process. Of major interest was information on rate processes (reductions, extraction, liquid/solid separation, heat exchange fouling, etc.); equilibrium relationships (distribution of metals and impurities in slag and matte phases, vapor/liquid equilibrium in tailings stripping, etc.) and their relationship to processing conditions such as temperature, pressure, and pH; and required residence times, yields, etc. from pertinent unit operations. The amount of these data available in the open literature varied for each process. Where data needed to develop the process configuration and material and energy balance were not available, the needed criteria were generated on the basis of engineering judgement and assumptions, knowledge of the state-of-the-art and/or a knowledge of analogous processes.

The following paragraphs introduce general assumptions and judgements made during the course of this study. The following items are discussed:

1) characteristics of nodules;

2) process rates and products;

3) process material and energy requirements;

4) process wastes;

5) potential for accidents with pollutant release; and

6) plant noise.

3.2 CHARACTERISTICS OF NODULES

3.2.1 Nodules Composition

The nodules composition assumed for this study is summarized in Figure 3.1. This consumption is a composite of various reported assays (Hubred, 1975; Sridhar, 1975; Kruger, 1975; Vasilckikov et al, 1965; Queneau, 1975; Granville, 1975; Meixner, 1974; and Beck et al, 1970) and would be suitable for use in either three- or four-metal process plants. It has been assumed that the nodules will be stored wet and will contain 40 percent moisture and 60 percent solids as fed to the process. The water is 5 percent surface water and 25 percent water contained within accessible pores which can be removed by drying at relatively low temperatures. The other 10 percent is chemically bound water which would require high temperature drying to remove.

3.2.2 Classification of Nodule Constituents

With reference to the assumed average nodules composition given in Figure 3.1, the constituent elements were classified for purposes of this study into four main groups. One group includes the major and value metals, comprising in total about 29 percent of the weight of the nodules. Another group, the potentially toxic constituent elements, comprise less than 1 percent of the nodules. It should be noted that the "potentially toxic" elements are chemically stable and bound in the nodule so that the nodule itself is "non-toxic". These elements occur as five pairs spread across the periodic table (see Figure 3.1). There is also a group of elements which are innocuous and nonminor (about 14 percent in total). Their presence must be accounted for in the gross material balances, because they constitute a substantial portion of some process streams, including plant wastes. "Gangue" might be an appropriate collective designation. Finally, there are the remaining constituents which occur in minor or trace amounts and which are nontoxic at that level. This last group amounts to only about 0.3 percent of the weight of the nodules, and the distribution of its members has not been followed through the flowsheets. Table 3.1 identifies the elements in their respective groupings. Their contents in the dried (but not calcined) nodules of assumed average composition sum to about 44 percent, the remainder being mainly oxide oxygen and chemically bound and pore water.

3.2.3 Analysis of Potentially Toxic or Hazardous Constituents

Five primary sources were consulted in the analysis to determine those constituents of manganese nodules which had to be followed in the processing operation because they have been identified as potentially toxic or hazardous. These sources are:

1. "EPA Hazardous Substances, Designation, Removability, Harmful Quantities, and Penalty Rates," Federal Register, December 30, 1975.

H																	He
Li	Be										Element Concentration*	B 0.024	C 0.08	N	O	F	Ne
Na 1.76	Mg 1.12	Al 2.16											Si 5.44	P 0.12	S 0.08	Cl 0.64	Ar
K 0.8	Ca 1.28	Sc 0.0008	Ti 0.36	V 0.032	Cr 0.0008	Mn 20.0	Fe 6.8	Co 0.16	Ni 1.04	Cu 0.88	Zn 0.10	Ga 0.0008	Ge	As 0.004	Se	Br	K
Rb	Sr 0.064	Y 0.024	Zr 0.048	Nb 0.0024	Mo 0.04	Tc	Ru	Rh	Pd	Ag 0.0002	Cd 0.0016	In	Sn 0.024	Sb 0.0024	Te	I	X
Cs	Ba 0.32	La 0.13	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl 0.016	Pb 0.04	Bi 0.0024	Po	At	Rn
Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm								

* Concentration based on wet (as-mined) nodule weight

FIGURE 3.1 ASSUMED COMPOSITION OF MANGANESE NODULES USED IN THIS STUDY

2. EPA Primary Drinking Water, Proposed Interim Standards, Federal Register, March 14, 1975.
3. U.S. Public Health Service Drinking Water Standards, 1962 (HEW Publication).
4. N.I. Sax, "Dangerous Properties of Industrial Materials," 4th edition, Van Nostrand Reinhold Company (New York, 1975).
5. Kirk-Othmer, "Encyclopedia of Chemical Technology," 2nd edition, Interscience Publishers (1970).

As a first step, the forms of the elements contained in the nodules and of the major elements in the process raw materials were enumerated. Table 119.5, "EPA Harmful Quantity Categories," of Source 1 was then culled for toxic or hazardous substances which are combinations of the elements present in nodules. The resulting list of some sixty inorganic substances proved to have limited usefulness for several reasons. In practically no instances would the indicated compounds occur at any stage of nodules treatment as distinguishable and isolatable entities. Further, substances which could be present and which are hazardous by reason of being chemically aggressive, for example, strong acid and strong caustic, would be introduced into the process as materials other than nodules.

TABLE 3.1

MAJOR CATEGORIES OF ELEMENTS IN MANGANESE NODULES USED IN THIS STUDY

Major and Value Metals	Manganese, Iron, Cobalt, Nickel, Copper, Zinc, Molybdenum	(∼29% total)
Innocuous Nonminor Elements	Sodium, Potassium, Magnesium, Calcium, Aluminum, Titanium, Silicon, Phosphorus, Sulfur, Chlorine	(∼14% total)
Known Toxic Elements, Chemically Bound	Barium, Lanthanum, Vanadium, Chromium, Silver, Cadmium, Thallium, Lead, Arsenic, Antimony	(∼0.5% total)
Innocuous Minor Elements	Boron, Carbon, Scandium, Strontium, Yttrium, Zirconium, Niobium, Gallium, Tin, Bismuth	(∼0.3% total)

A guide to the degree of toxicity of selected nodules constituents was obtained by reference to the EPA Primary Drinking Water Standards. For the inorganic materials of concern to this study, the concentrations are represented in Table 3.2. Other than for mercury, not present at a perceptible level in the standard nodules, the lowest permissible concentration is 0.01 mg/l, or approximately 0.01 ppm. Barium is considered to be appreciably less toxic (as demonstrated by the widespread use of $BaSO_4$ in medical x-ray examination) than the other cations listed, but its assumed content of 0.32 percent in the nodules indicated that it be flagged as potentially toxic.

There are other nodules constituents known or suspected to be toxic, for example, thallium. A check of Sax's Handbook and the Kirk-Othmer Encyclopedia confirmed this classification for thallium and suggested the inclusions of lanthanum (not highly toxic but 0.13 percent of the nodules), vanadium (0.032 percent) and antimony (0.0024 percent). As a result of this analysis, a list of ten potentially toxic nodules constituents was developed. In considering process stream and waste compositions, it was recognized that recommended concentration limits (USPHS) in drinking water exist for several of the major and value elements present in nodules. These are (mg/l or ppm): Manganese (0.05), Iron (0.3), Copper (1.0), Zinc (5.0).* The distributions of these elements form part of the major material balances.

TABLE 3.2

DRINKING WATER STANDARDS FOR INORGANIC SUBSTANCES

Substance	Limits mg/l or ppm	Concentration in Sea Water ppm
Arsenic	0.05	0.01 to 0.02
Barium	1.0	0.05
Cadmium	0.01	N/A
Chromium (VI)	0.05	N/A
Lead	0.05	0.004
Silver	0.05	0.003

3.3 PROCESSING RATES AND PRODUCTS

3.3.1 Processing Rates and Products

Capital and operating cost estimates and evaluations of market impacts as described in Chapter 2.0 indicate that three-metal plants would be built with capacities of up to three million tonnes of nodules per year, while four-metal plants would have a capacity of up to one million tonnes per year. The material and energy balances developed here are based on processing approximately these quantities of materials, as shown in Table 3.3. The anticipated plant stream factor, or percent of time the plant is in operation, is approximately 90 percent, with full production on 330 days per year.

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*At the indicated low levels, the presence of these elements is objectionable on primarily aesthetic or practical grounds. These elements discolor the water or give it a bad taste.

TABLE 3.3

PROCESSING RATES

3-Metal Plant	Tonnes Per Year	Tons Per Year
Wet (as-mined)	3.7×10^6	4.1×10^6
Dry	2.2×10^6	2.5×10^6
4-Metal Plant		
Wet (as-mined)	1.1×10^6	1.25×10^6
Dry	0.7×10^6	0.75×10^6

3.3.2 Product Forms

It has been assumed that copper and nickel would be electrowon from solution to produce a product of cathode specification, a common commercial form of these metals. Since none of the leach solutions would be pure enough to permit direct electrowinning, metals separation schemes are required to produce electrolytes of acceptable purity. It has been assumed that these schemes would be based on processes which are currently in use in non-ferrous metal production.

Cobalt would be produced as a hydrogen reduced, briquetted powder. Minor amounts of nickel would also be produced in this form. Minor amounts of impure zinc and copper sulfides would be produced as a by-product of the cobalt recovery operations. These could be sold to conventional smelters for further processing.

Manganese would be produced, in the four-metal process routes, as either ferromanganese or electrolytic manganese. Ferromanganese is an iron and manganese mixture and is the most common form of manganese in commerce. Electrolytic manganese is essentially pure manganese metal. A possibility also exists that manganese could be recovered from leach tailings of the three-metal process routes. However, this option has not been considered here, since no data have been published on the amenability of leached tails from these processes to upgrading for manganese recovery.

3.3.3 Process Byproducts

The process routes have been specified to minimize the byproduct formation and maximize the re-use and recycle of lixiviants. While this could require the purchase of additional process materials and the consumption of additional energy, it eliminates the need to establish a marketing operation other than one devoted to nonferrous metals.

3.4 PROCESS ENERGY AND MATERIAL SOURCES

3.4.1 Energy Sources

It has been assumed that the primary energy source for onshore nodules processing plants will be coal. While the energy requirements are comparable to many existing plants of various types, access will be required to rail systems for the delivery of the required amount of coal, and provisions will be made at the plant site for its storage and reclamation, as is common industry practice. The coal composition assumed for this study is summarized in Table 3.4.

TABLE 3.4

ASSUMED COAL COMPOSITION

Type: High Volatile Bituminous C

Analysis:	65%	Carbon
	6%	Hydrogen
	18%	Oxygen
	1%	Sulfur
	1%	Nitrogen
	9%	Inerts

Higher Heating Value: 11,400 Btu/lb or 6,300 kcal/kg

Petroleum products for onshore processing are considered to be used only by plant vehicles and for minor process uses for which the combustion of coal is not a convenient way to deliver energy. Similarly, fuel oil or gas would be used only for those process applications for which a clear economic and processing advantage can be shown versus the use of coal. In all cases, however, the fuel oil equivalent of the coal consumed has been computed and reported.

The metals recovery sections of the nodules processing plants, in particular, are energy intensive and high consumers of power, while other operations demand large quantities of process steam at intermediate to low pressures. It has been assumed that steam will be raised at high pressure and expanded through back-pressure turbines to provide for the delivery of both process steam and some process power. The balance of process power requirements in onshore plants will probably be met by purchases from local utilities in order to minimize the capital investment in plant facilities which are not directly required in the production of metals from nodules.

3.4.2 Process Materials and Supplies

The consumption of process materials and supplies directly used in nodules processing has been estimated in developing the material balances. The composition of the major materials is summarized in Table 3.5. No attempt has been made to calculate the consumption of maintenance materials and replacement parts such as furnace refractories, new anodes, etc., but the annual cost of these items typically is about 1-2 percent of the capital cost of the plant.

With the exception of the reduction/hydrochloric acid leach process, the plants are assumed to be self-sustaining, requiring only make-up of lixiviant and supplies consumed in processing. For the hydrochlorination route, it has been assumed that a buyback arrangement exists for the chlorine generated in the process.

TABLE 3.5

COMPOSITION OF PROCESS MATERIALS AND SUPPLIES

Gases

Ammonia - Commercial Anhydrous
Hydrogen - Commercial 99% Minimum
Hydrogen Sulfide - (Liquid) Commercial 97.5%
Chlorine - (Liquid) Commercial 99.5%
Nitrogen - Commercial

Liquids

Organic - Liquid ion exchange/chelating agent dissolved in diluent at concentration appropriate to each process.
Sulfuric Acid - Commercial 93%
Nitric Acid - Commercial 60%
Sodium Hydroxide - Commercial 50%
Fuel - Vehicular and combustion fuel as required
Oxygen - Commercial

Solids

	Limestone		Lime	
% Calcium	80	(Calcium Carbonate)	79	(Calcium Oxide)
% Magnesium	15	(Magnesium Carbonate)	12	(Magnesium Oxide)
% Inerts	5		9	

Flocculants - Commercial Polyelectrolytes
Additives - Commercial Electrowinning Additives
Sodium Sulfate - Anhydrous, Photo Grade
Boric Acid - Commercial Granular, 99.9%
Carbon - Commercial Activated C
Borax - Technical, Anhydrous, 99%
Electrode Paste
Salt - Commercial Rock Salt

3.4.3 Water

It is assumed that an ample supply of water for consumptive use is available from a nearby source. It should be noted that consumptive water need not be of drinking water quality. Treated municipal waste or agriculture runoff water, if low enough in salinity, could be used with proper in-plant pretreatment. Water with a hardness of 250 mg/l (250 ppm) calcium carbonate equivalent and carrying 200 mg/l (200 ppm) suspended solids has been assumed. The majority of the consumption is required for evaporation in cooling towers and to carry tailings and other process solid wastes as slurry to disposal.

3.5 PROCESS WASTES

3.5.1 Process Wastes and Emissions

It is assumed that the design of any nodules processing plant will be sufficient to ensure compliance with applicable federal and local regulations concerning the discharge of solid, liquid and gaseous effluents. For the present study, we have assumed that this will require that:

1. All combustion gases will be scrubbed with limestone slurry for sulfur removal and that the combustion processes will be controlled so as to permit compliance with nitrogen oxide and sulfur oxide emission regulations. Alternate scrubbing techniques are, of course, possible.

2. Process wastes which are combustible will be burned on site.

3. Adequate measures will be taken for dust control at appropriate places within the process, with effluents discharged after further treatment, as required.

4. Gaseous emission control in high temperature operations will be achieved by the use of hooding and high volume ventilation, with the fugitive gases being scrubbed prior to release to the atmosphere, as required.

5. All vents on process tankage will be manifolded to scrubbers or protected with conservative units.

6. Process solid and liquid waste, including plant run-off, will be combined with leached tailings or granulated slags, neutralized if required, and piped to lined tailings ponds for containment.

3.5.2 Waste Treatment

The objectives of this analysis are to identify alternative waste treatment methods that could be used by industry to render the wastes innocuous, and to describe and determine the impact that alternative methods of waste handling would have on the overall plant material and energy balances and on the characteristics of liquid and solid effluents. Since the base case process descriptions assume that gaseous effluents are treated to the required degree, they are not considered herein.

The following waste treatment alternatives were reviewed for their impact on the overall process material and energy balances.

1. Separation and subsequent treatment of the various wastes produced in the process as opposed to combining waste streams which is the base case.
2. Modification of the basic process configurations to control waste generation in-process.
3. Precipitation or fixation of soluble toxic elements with direct discharge of treated wastes into containment structures.
4. Precipitation of soluble toxic elements followed by washing of solid waste to remove soluble innocuous and toxic elements for separate treatment or control.
5. Precipitation of toxic elements followed by washing and drying of solid wastes.

The first two alternatives were eliminated from further consideration on the basis of the information provided in the next two paragraphs.

The toxic elements are widely dispersed in process waste streams. Furthermore, by far the largest volume waste streams in all processes, leached tails, slags, and lime-boil solids, all contain toxic elements. Therefore there is little to be gained by separating process wastes prior to treatment and the first option has not been considered further.

The majority of the toxic elements leave the process in solid process waste streams. The toxic elements occur mainly in the solid residues from leaching and precipitation steps. They are also fixed in neutralization and lime-boil steps and incorporated in slags. The distribution of each element in the various processes is largely inherent in the process chemistry, and very little can be done to alter its ultimate fate without major structural changes within the process. Some changes can be made on the distribution of toxic elements which had been solubilized,such as in more efficient washing of leached tails. However this only results in retention of toxic elements within the process loop where they would be removed, to a certain degree, in subsequent precipitation steps. Also, no sequence of washing steps is completely effective and attempts to reduce concentrations by even one order of magnitude would be extremely costly. Furthermore, some purge point must be provided within all the processes for the elimination of soluble innocuous materials, such as sea salts, to prevent their build-up to saturation levels. Such an occurrence would cause significant operating difficulties, since their precipitation could not, in general, be controlled and would adversely impact process viability. Thus, it is not likely that significant changes could be made in the nature of the process waste without major modifications of the process routes. Since the waste products would still require further treatment, option 2 which involves major process alterations was not considered further as a basic treatment technique, per se.

The waste treatment alternatives considered in more detail include precipitation of soluble toxic elements with direct discharge of treated wastes (option 3); precipitation of soluble toxic elements followed by washing of solid waste to remove soluble innocuous and toxic elements for separate discharge (option 4); and precipitation of toxic elements followed by washing and drying of solid wastes (option 5).

Precipitation of toxic elements, option 3, could be achieved by treating the combined process waste streams with slaked lime. Sufficient lime would be added to remove soluble sulphates as gypsum and raise the solution pH to a sufficiently high level to precipitate metal hydroxides. It is assumed that, under these conditions, anion-forming elements such as arsenic, vanadium, and molybdenum would also be fixed, although this is somewhat more problematical. Other metal hydroxides, such as magnesium, would also be precipitated but alkali metals and alkali earths would remain in solution as chlorides, hydroxides, and sulphates to their solubility limits. An excess of lime could be added to stabilize the precipitated toxic elements, including heavy metals, against redissolution after disposal.

Option 4 which involves removal of soluble, non-toxic compounds from the processed solid wastes. In this option washing by countercurrent decantation in a thickener train similar to that used in tailings washing could be used. Washing would be carried out with reclaimed, essentially solids-free water. The liquid in the washed wastes slurry would contain approximately 200 mg/l (or ppm) innocuous dissolved solids, which is the level assumed for the process make-up water, and approximately 1 mg/l (or ppm) total content of toxic elements, including heavy metals. Soluble toxic elements would be removed from the wash water by sorbtion on activated carbon, or a suitable ion exchanger, which can be regenerated by hydrochloric acid. Recovery can be made by evaporation and crystallization for disposal as solid chloride salts. Salt-free water for recycle would be recovered from the dilute solution of soluble innocuous salts by reverse osmosis and evaporation.

Solid waste drying (option 5) is an additional step which would be performed on the washed wastes after the operations described in option 4. This drying step would require a substantial increase in coal consummed. Although technically feasible, it is unlikely that this option would be considered by industry because of the high energy costs involved, unless disposal of dried wastes were mandated by regulatory authorities.

3.6 POTENTIAL ACCIDENTS WITH POLLUTANT RELEASE

The nodule reduction/refining processes utilize some materials which would be considered environmentally detrimental if they escaped from the plant. These include mineral acids, ammonia, kerosene, hydrogen sulfide, and chlorine. An environmental hazard analysis focuses upon accidents which have the potential of releasing such materials into the environment. Accidents which would release pollutants such as ordinary smoke (inert particulates and gases) into the environment are considered outside the scope of this hazard analysis. Primarily, the potential accidents of concern would involve large releases of liquids and gases of the types previously mentioned, or a smaller amount of sulfuric acid mist released if a pressure vessel were to rupture. Industrial accident statistics serve as a guideline to those accident situations which could result in releases since the nodule processing plants are similar in terms of volumes of potentially hazardous materials in process and in inventory to other similar industrial plants.

Basic environmental safeguards in the design of the nodule plant are assumed, including avoidance of unusual foundation problems, flood zones, active faults, etc. Containment of spills from stored hazardous and toxic reagents by diking, berms, and sumps, as required by Federal regulations, would be incorporated and a contingency plan for controlling and containing spills is assumed to be in effect, along with personnel training. Avoidance of elevated and slope sites for large volume items, which could create high velocity flows in the event of rupture, is an example of a simple design criterion which can reduce the chance of large liquid spills.

A sump which could provide complete environmental protection, i.e., sized and designed to receive the full fluid inventory of the plant, is not likely to be affordable in terms of space or cost unless the tailing pond can be placed adjacent to the site and situated so that gravity flow from the plant is possible. However, an emergency standby sump at the site to provide a two-day process surge for tailings pipeline shutdown could also create important spill protection for the site.

The materials which could be released are not exotic organic substances of high toxicity and persistence, such as pesticides. Therefore these plants have less potential danger to their surrounding enviornment than do some large petrochemical plants. The liquid ion exchange reagents would be expected to degrade benignly when dispersed in the atmosphere. The large volumes of liquids are generally acidic or alkaline solutions with varying amounts of heavy metals. Contamination of a large watershed area might cause short-term adverse effects. However, the long-term problems could be minimal, with the possible exceptions being fragile local ecosystems in the drainage path near the site and watersheds supplying potable water.

Toxic gases which could be released in a system rupture could spread to considerable downwind distances at undesirable concentrations in the event of large volume releases under stable atmospheric conditions (adverse for dispersion). The hazard is greater from storage accumulations than from plant processes because of the volumes involved. However, the quantities of hazardous gases that are stored, such as chlorine or hydrogen sulfide, are very common in industrial areas and even in large water treatment plants. Therefore the process plants do not represent a special hazard.

The exception to this pattern is the hydrogen chloride leaching process, where substantial inventory of hydrogen chloride or chlorine gas could be released from the process. However, plant requirements may well involve siting close to chlorine plants, where such a the hazard exposure is already present. It also is not necessarily realistic to expect that the environmental risks could be reduced by decreasing the volumes in storage.

Rail shipment of toxic gases (generally as pressurized liquids) is less risky than truck shipment. Barge shipment is even safer. The lesser-risk methods require greater storage volumes at the site. Transportation hazards analysis, which might demonstrate this quantitatively, is beyond the present scope, which is limited to problems within the plant boundaries. The primary mitigating factors for the gaseous hazards would be avoidance of sites with adverse dispersion characteristics or, alternatively, avoidance of populated zones, protection of storage vessels from sources of rupture, and assurance of storage vessel reliability.

Large-scale toxic gas releases from storage are historically rare, with a failure rate estimated to be of the order 10^{-5} per year per installation (Simmons, et al , 1974). Another way of stating this risk is to say that if 10 such plants were in existence, there would only be one gaseous release every 10,000 years, on the average.

For each process, the release exposure is expressed in terms of the type and quantity of materials in storage and potential accidental release statistics. Where feasible, a maximum potential size of release and the frequency of occurrence have been estimated. Most of the maximum risk situations require hypothesizing multiple failures in the system, such as might occur in large seismic events or in explosions. Even some of these may be mitigated by protective systems.

3.7 NOISE ASSESSMENT

The five chemical processing schemes for the recovery of manganese and other metals from ocean nodules were reviewed for their noise emission characteristics.

Detailed designs of plants based on these processes have not been developed; hence, details of equipment types and usages are not available. Thus, noise levels from these processing plants can only be estimated. The major noise processing equipment can be grouped into the following general categories:

1) Fluid handling equipment (i.e., pumps, mixers, and agitators, etc.);

2) Gas handling equipment (i.e., compressors and fans, etc.);

3) Material handling equipment (i.e., mills and conveyors, etc.); and

4) Energy conversion equipment (i.e., combustors).

The power requirements of major equipment categories were estimated from designed processing rates for various plant unit operations. These data were obtained from the detailed flow sheets and line tables, which are presented in Volume III. Based on the power requirements of the equipment, estimates of their noise levels are made using data from published literature (such as Harris, 1957, and Magrab, 1975). However, it should be noted that since equipment types cannot be specifically defined, noise levels are only "order of magnitude" estimates.

Equipment emitting high noise levels would be either enclosed in a building or located outdoors. In this analysis, it is assumed that fans, compressors, and pumps would be enclosed by housings with approximately 30 dB attenuation. Induced draft fans and cooling towers would also be quieted by silencers with approximately the same attenuation capabilities. Indoor noise sources would be subjected to an additional attenuation of approximately 20 dB resulting from an assumed metal plant building. It is therefore anticipated that indoor noise sources would not contribute significantly to outdoor ambient sound levels. The principal noise sources contributing to the ambient sound would be unenclosed conveyors, feeders, and fans.

The noise levels generated during the operation of each processing plant was estimated by combining, on an energy basis, the sound energy of each individual noise source. An A-weighted sound level spectrum was used. Noise sources were assumed to be 305 meters (1000 feet) from the center of the plant. We assume that processing plant sites as a minimum would be rectangular in shape and approximately 730 by 980 meters (2400 by 3200 feet) in size. The noise levels can then conservatively be interpreted as the noise contribution from the processing activities to the ambient sound at the plant boundary.

3.8 AESTHETICS

A nodule plant would be classified as a heavy industrial plant. Depending on whether the plant was a 3-metal or 4-metal plant, the plant would occupy from 40 to 80 hectares (100 to 200 acres) of land. Most of the plant facilities such as crushing, washing, leaching, roasting, boilers, smelting and metal recovery equipment; and noise makers such as fans, pumps and motors would be located inside buildings. These buildings and facilities such as stacks, ore and material stockpiles, some reagent storage tanks, and rail lines would be visible from the plant boundary. Stacks up to a few hundred meters (several hundred feet) high and buildings, stockpiles, storage tanks and the like up to 3 to 4 stories in height would be typical. Small lagoons holding fresh make-up water or slurried wastes could also be visible on-site. Most likely a wide buffer zone of land would be purchased around the plant so that none of the plant facilities would be directly adjacent to public roads, right-of-ways, or other developments.

4.0 REDUCTION/AMMONIACAL LEACH PROCESS

4.1 INTRODUCTION

The reduction/ammoniacal leach process would recover copper, nickel and cobalt from nodules. This process is a modification of the well established Caron process which is used to recover nickel from laterites. The major difference is in the metals separation and purification steps which extends elements of existing technology to a new application in nodules processing. The quantities and types of materials and supplies required for this process are not large by industry standards and all would be readily available via truck and rail haulage to the plant site.

This process is illustrated by a simplified block diagram on Figure 4.1. The first process step consists of ore grinding and drying. The value metals are liberated by an oxidizing ammoniacal/ammonium carbonate leach following high temperature reduction of manganese dioxide by a carbon monoxide/hydrogen rich (producer) synthesis gas. Copper and nickel are coextracted by liquid ion exchange reagents and selectively stripped and recovered as electrowon cathodes. Cobalt is recovered from the nickel and copper free pregnant liquor (the raffinate from the nickel and copper extraction) by precipitation with hydrogen sulfide and is recovered from the sulfide precipitate by selective leaching and hydrogen reduction along with some nickel, zinc and copper. The metal-free raffinate is recycled to provide leach liquor and for washing tailings from the process. Ammonia and ammonium carbonate are recovered from leach tailings by contacting the mixture directly with steam to boil off the volatile compounds (steam stripping).

In subsequent paragraphs of this chapter a summary of the essential aspects of this process are described. This includes a more detailed description of the process; a summary of the plant inputs and outputs; a description of the plant support requirements; a summary of waste treatment alternatives and their impacts on material and energy balances, accidental release analysis; and an assessment of the noise generated by the plant. A detailed description of this process is included in Volume III.

4.2 PROCESS DESCRIPTION

An outline of the reduction/ammonia leach process is shown on Figure 4.2. The first step in this process is ore preparation and grinding followed by a high temperature (625°C, 1157°F) reduction of manganese dioxide, the major mineral in nodules, to manganese oxide by producer gas, which is rich in carbon monoxide. The effect of this reduction is to disrupt the mineral structure and release the contained metals. The metals are removed from the reduced nodules by dissolution into a strong aqueous solution of ammonia (10 percent) and carbon dioxide (5 percent), at low temperature (40°C, 104°F) and atmospheric pressure.

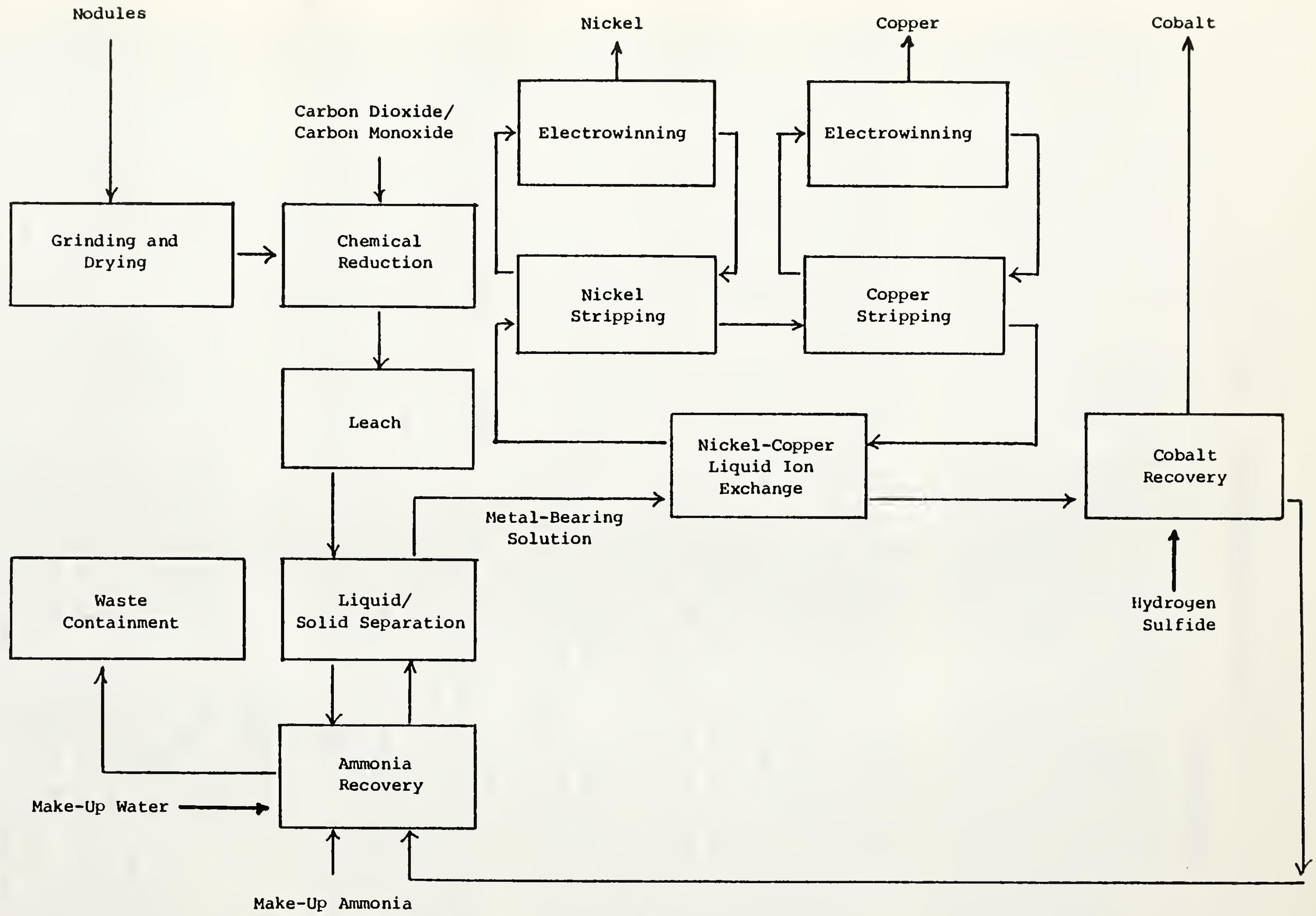

FIGURE 4.1 REDUCTION/AMMONIA LEACH PROCESS

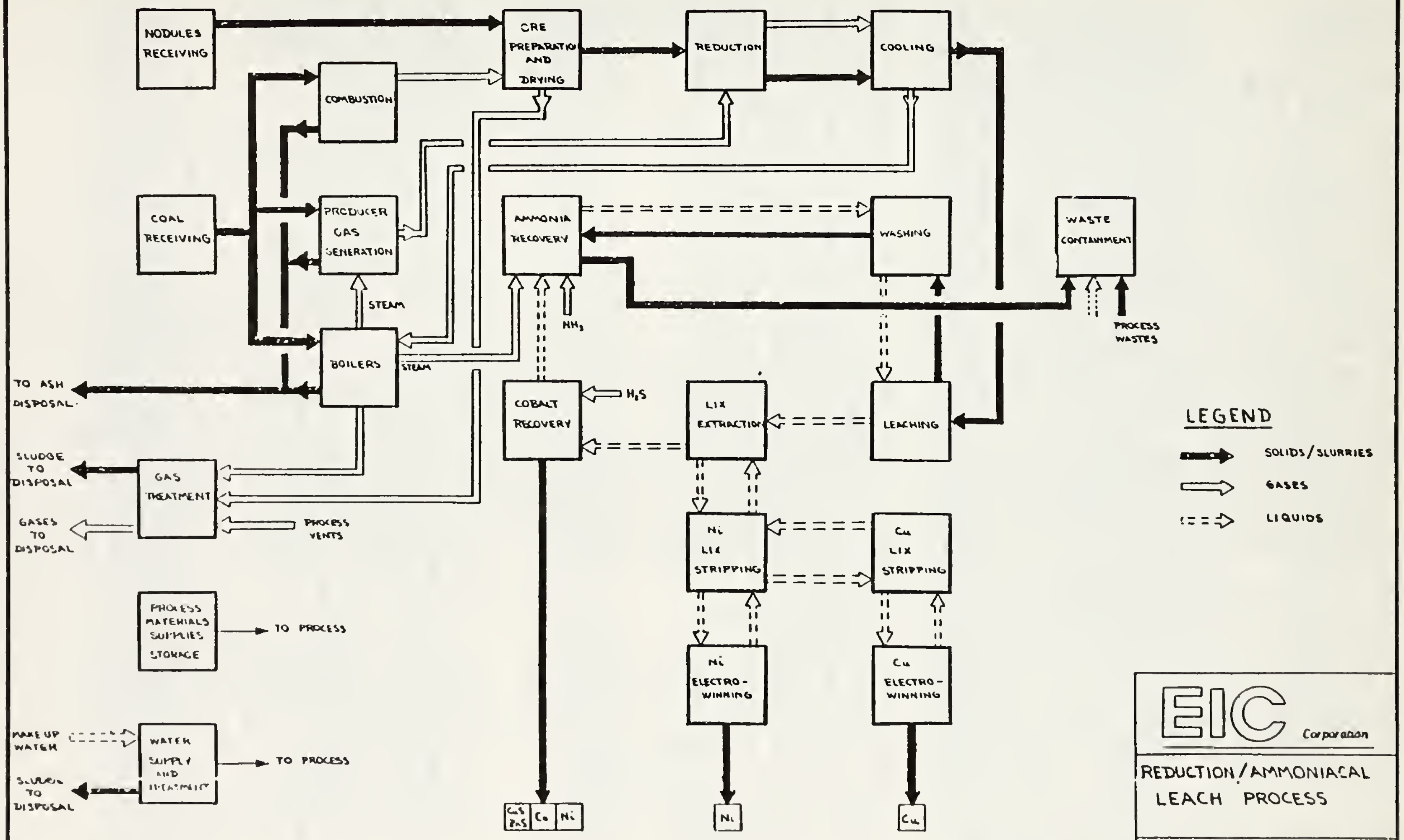

FIGURE 4.2

EIC Corporation

REDUCTION/AMMONIACAL LEACH PROCESS

PROCESS OUTLINES

NC-0013-AM

REV. 0

The metal-bearing solution is decanted from the nodule residue and subjected to a series of purification steps in which it is contacted with an organic medium which selectively and separately removes the copper and nickel. The metal values are then transferred to acid aqueous solutions in the form of copper sulfate and nickel sulfate. The metal products, cathode copper and nickel, are produced from these solutions by electrodeposition.

Cobalt is then recovered from the aqueous ammonia/carbon dioxide solution by contacting it with hydrogen sulfide, which precipitates the insoluble sulfides of cobalt as well as small amounts of the sulfides of copper, nickel, zinc, and other metals not removed in previous steps. The solids are removed from the aqueous ammonia/carbon dioxide solution and contacted with air and hot (100°C, 212°F) sulfuric acid to selectively redissolve the cobalt and the small amount of nickel present. The undissolved sulfides are sold as minor products and the cobalt and nickel are recovered from solution in powder form by selective reduction with hydrogen at high pressure (34 atm) and temperature (185°C, 365°F).

The reduced nodules residue, from which the major portion (98 percent) of the soluble metals has been removed, is contacted with steam (at 120°C, 248°F, 2 atm pressure) to remove residual ammonia and carbon dioxide. The ammonia/carbon dixoide/steam mixture is condensed and, together with the aqueous ammonia/carbon dioxide mixture from which cobalt had been removed, is recycled to extract more metal values from freshly reduced nodules. The steam-stripped nodule residues are combined with smaller amounts of other process solid and liquid wastes and sent to containment.

Plant services include facilities for generating the producer gas used in nodule reduction, raising the necessary steam and part of the power required for process use, supplying the make-up water and cooling required, and providing for materials handling for process materials and supplies.

The high temperature reduction of nodules with simulated producer gases and subsequent extraction of metals with ammonia/carbon dioxide solutions has been extensively studied and reported. This approach is basically the same as is currently used in recovering nickel from laterites by the Caron process and can be considered a variation of currently available technology. The metal separation and purification scheme, however, is specific to nodules and is complicated by the chemical similarity of copper, nickel, and cobalt. Separation and purification of copper and nickel by selective extraction with organic compounds (liquid ion exchange reagents) is currently practiced in the extractive metallurgy of copper and nickel. However, in these cases the aqueous solutions contain primarily one metal, the others being treated as impurities, not products. Cobalt recovery from precipitated mixtures of nickel and cobalt sulfides derived from laterites is also currently practiced. The details of the procedures used to purify the leach solutions prior to reduction, however, would differ somewhat from those used for nodules because of the differences in amount and content of impurities. The generation of producer gases from coal or oil for the reduction of nodules and all other plant services represent the utilization of known technology, essentially without adaptation.

A major alternative to the proposed process configuration involves the low temperature, high strength aqueous reduction of the nodules using low pressure carbon monoxide gas. This option is presented in Chapter 5.0 and is known as the Cuprion process. Other variations in the process are possible, particularly with respect to the specific metals separation and purification schemes used. However, they would likely have only minor impact on overall process inputs and outputs.

4.3 PLANT INPUTS AND OUTPUTS

The major items which comprise the material and energy balances for the reduction/ammonia leach process are summarized in Table 4.1.

TABLE 4.1

MAJOR PLANT INPUTS AND OUTPUTS

	MAJOR INPUTS	
Nodules	3.7×10^6 mtpy	4.1×10^6 tpy
Coal	706×10^3 mtpy	775×10^3 tpy
Water	6.0×10^6 m^3/yr	1.6×10^9 gpy
Gases	8.4×10^6 mtpy	9.3×10^6 tpy
Liquids	4.5×10^3 m^3/yr	1.2×10^6 gpy
Solids	27×10^3 mtpy	30×10^3 tpy
Purchased Power	23.5×10^3 kW	
	MAJOR OUTPUTS	
Solid Wastes	2.6×10^6 mtpy	2.8×10^6 tpy
Liquid Wastes	3.4×10^6 m^3/yr	900×10^6 gpy
Stacked Offgases	20×10^3 m^3/min	705×10^3 scfm
Low Level Emissions	1.9×10^3 m^3/min	67×10^3 scfm
Cooling Tower Evaporation	3×10^3 m^3/min	100×10^3 scfm
Copper	27×10^3 mtpy	30×10^3 tpy
Nickel	33×10^3 mtpy	36×10^3 tpy
Cobalt	3.9×10^3 mtpy	4.3×10^3 tpy

The distribution of services required within the plant is summarized on Table 4.2. The services include process power, process steam, cooling water and process water. The process water is consumed within the plant while the cooling water is recycled.

TABLE 4.2

SERVICES PROFILE

	Process Power	Process Steam		Cooling Water		Process Water	
	kW	kg/hr x 10^3	pph x 10^3	m^3/min	gpm	m^3/min	gpm
Ore Preparation & Drying	3,700	-	-	-	-	-	-
Reduction	4,500	-	-	-(1)	-(1)	1.9	500
Leaching	1,650	-	-	5.3	1,400	-	-
Tailings Washing	450	-	-	-	-	0.03	7
Liquid Ion Exchange	650	10.7	23.5	3.0	800	0.08	21
Copper Electrowinning	9,500	7.5	16.5	3.4	900	0.06	15
Nickel Electrowinning	15,800	4.3	9.5	0.4	100	0.09	25
Cobalt Recovery	800	18.9	41.5	10.2	2,700	(0.06)	(17)
Ammonia Recovery	650	117.5	258.5	105	27,800	4.4	1,166
Materials Handling	950	-	-	-	-	0.09	23
Services & General Plant Use	9,950	77.5	170.5	13.2(1)	3,500(1)	5.9	1,560
	(25,100)(2)	(50)(3)	(110)(3)				
TOTAL	23,500	236	520	141(4)	37,200(4)	12.5(5)	3,300(5)

(1) 32.5 x 10^6 kcal/hr (130 x 10^6 Btu/hr) to boiler feed washing heating.

(2) Generated internally.

(3) Used internally in power generation.

(4) 84 kcal/hr (335 x 10^6 Btu/hr), non consumptive use.

(5) Consumptive use.

The composition of the output streams which constitute process wastes is summarized on Tables 4.3 and 4.4 for the solid and liquid and gaseous wastes, respectively. These compositions were derived from the overall plant material balance and are presented for only the major materials in the process. Where trace amounts of a material are indicated, it has been assumed that previous removal steps will have reduced it to a level which is either acceptable for discharge directly or it is present in amounts too low to quantify within the accuracy of the methods used in this study.

By far the largest quantity of wastes are the leached tails (the nodules less the value metals removed in processing). In the metals industry it is common practice to slurry tails along with other waste for transport to and disposal in a tailings containment area. If this practice is followed, the total volume of tailings is approximately equal to the volume of incoming nodules. The leached tails are assumed to be a combination of hydrous slimes and settleable sludges which contain mostly inert and non-toxic clays and manganese carbonate plus sea salt and minor amounts of potentially toxic elements which entered with the raw nodules and unextracted value metals.

Smaller but significant amounts of combustion and gasification ash, offgas scrubber solids, lime boil solids and solids generated by water softening will be added to the tailings stream. The materials are all relatively inert and are similar to the types produced by any coal-fired power plant. These wastes would pose no significant disposal problem and would be transported along with the tails to a tailings containment site.

As previously stated in this report, the gaseous wastes will be controlled to meet all emission regulations. Therefore gases are of no concern outside the plant.

A summary of the flows and distributions of potentially toxic elements for the reduction/ammonia leach process is presented in Table 4.5. Although the mass flow rates are large, the concentrations of any of the listed elements is small due to the large throughput in the plant. Several of the elements, silver, cadmium and thallium are essentially totally contained in the products and as such are of no further concern. All of the barium and nearly all of the lanthanum, vanadium, chromium, antimony and lead pass through the process in essentially basic chemical form the same as they entered in the raw nodules and as noted earlier, a nodule as mined is considered "non-toxic".

In summary, the tailings would contain significant amounts of elements which could be potentially toxic. However, these would be precipitated as stable compounds which along with the other solid tailings can be safely stored in a lined tailings disposal facility.

TABLE 4.3

CHARACTERIZATION OF SOLID AND LIQUID WASTES

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHED TAILS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	GASIFICATION ASH (slag)	COMBUSTION ASH	OFFGAS SCRUBBER SOLIDS
Solid Flows	mtpd	2.2	0.11	0.11	7,400	56	7.7	130	36	65
	tpd	2.4	0.12	0.12	8,200	62	8.5	144	40	72
Liquid Flows	m^3/hr				384	14	1	20		10
	gpm				1690	62	4	90		45
Temperature °C/°F		25/77	40/104	25/77	50/122	50/122	25/77	80/176	90/194	75/167
Constituents:		. Lead . Lead Sulfate . Manganese Dioxide . Etc.	. UNK	. Carbon	. Manganese Dioxide . Manganese Monoxide . Magnanese Carbonate . Iron Hydroxide . Clays . Ammonia . Carbon Dioxide . Copper . Nickel . Cobalt . Zinc . Molybdenum . Sea Salt	. Gypsum . Aluminum Oxide . Molybdenum . Sea Salt . Magnesium . Sodium . Boric Acid . Cobalt	. Limestone . Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Calcium Sulfite . Calcium Sulfate . Silica . Aluminum Oxide . Manganese Dioxide . Manganese Carbonate . Magnesium
Chemical Characteristics:		A			A, D	A, D, E	B, E	A, B	A, B	A, B, D, E
Physical Characteristics:		D			A, B	B	B	C		B

KEY:

Chemical Characteristics		Physical Characteristics	
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 4.4

COMPOSITION OF GASEOUS EFFLUENT STREAMS

Stream	Dust Control Exhausts	Copper Tank House Exhaust	Nickel Tank House Exhaust	Leach Reactor Vent	Dryer Exhaust	Reduction Reactor Vent	Ammonia Scrubber Vent	Stacked Gases	Dryer Offgas	Producer Gas	Reduction Offgas
m^3/min	1,470	130	146	150	7	0.6	954		5,050	4,110	7,080
Total Flow SCFM	52,000	4600(1)	5200(1)	5300	300	20	33,700	575,000	178,000	145,000	250,000
Temp., °C	25	50	50	40	90	40	25	145	175	825	125
°F	77	122	122	104	194	104	77	293	347	1,517	257
Press, Atmosphere	1	1	1	1	1.1	1.1	1.1	1	1.05	1.7	1.05
% Oxygen	21	7	7.5	16	2		20	5	10		
Nitrogen	79			77	43		77	53	58	49	30
Ammonia							TR	TR		0.2	0.1
Carbon Monoxide								TR		18	0.8
Carbon Dioxide					6		TR	6	5	8	7
Methane										4	2
Hydrogen			0.5			10				9	5
Water		93	92	7	48	90	3	36	27	11	55
Hydrogen Sulfide, Sulfur Dioxide									0.03	0.4	0.1

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(1) Cell exhaust only, excluding building ventilation.

TABLE 4.5

DISTRIBUTION OF POTENTIALLY TOXIC ELEMENTS

Element	Input Rate To Plant kg/day	Input Rate To Plant (lbs/day)	Distribution As Percent Reporting To Waste	Distribution As Percent Reporting To Product
Barium	34,500	76,000	100	0
Lanthanum	14,100	31,000	100	0
Vanadium	3,450	7,600	50	50
Chromium	86	190	90	10
Silver	27	60	0	100
Cadmium	172	380	3	97
Arsenic	436	960	90	10
Antimony	263	580	50	50
Thallium	1,730	3,800	11	89
Lead	4,360	9,600	90	10

4.4 PLANT RESOURCE REQUIREMENTS

It is estimated that the total plant facility including processing and support facilities but excluding long term waste containment areas, will require approximately 80 hectares (200 acres) of land. Within the hydrometallurgical processing area, the plant layout will involve equipment densities which are typical for the chemical processing industry. Separate processing buildings would be provided for the liquid ion exchange operation and for copper and nickel electrowinning and cobalt recovery. Nodule drying and reduction and ammonia recovery would be outside installations, as would be the coal gasification operation. A boiler house/power house and banks of cooling towers would be located adjacent to the chemical process areas, and offices, laboratories, maintenance shops, warehouses and control houses, and a change house/cafeteria and parking area would also be located close to the main processing area. While the aforementioned facilities would require about 8 to 20 hectares (20-50 acres) of land, the plant layout is dominated by the requirement to provide materials storage areas and for the thickeners in the leaching and washing section. Approximately 10 hectares (25 acres) would be required for the thickeners. The nodules storage and decant ponds, the coal and lime and limestone storage area, and a plant run off and emergency waste storage area would require at least 20 hectares (50 acres), including margins, of relatively flat terrain. No unusually tall structures would be required in the process areas, but the main stack height could be significant, depending on local meteorological conditions.

The materials movements in and out of the plant are significant. Excluding raw nodules and waste products, in excess of 2200 mtpd (2400 tpd) of fuels and process materials are brought in and 180 mtpd (200 tpd) of products are shipped out. Thus, the transportation network supporting plant operations must include highway and rail connections capable of supporting considerable traffic. The coal, lime and limestone, ammonia and hydrogen sulfide, and sulfuric acid would be delivered and copper and nickel would be shipped by rail. Most other materials and supplies would be trucked.

Manufacturing operations within the plant will be on a three shift, 365 day per year basis. Downtime for maintenance and repair throughout the year are assumed to be such that full production will be obtained for the equivalent of 330 days per year. It is estimated that about 500 people will be employed in the facility, including operating and maintenance labor, supervision, and plant general and administrative personnel. The mix of skill levels would be typical of a chemical processing plant, with about one third being skilled tradesmen and lead operators, one third unskilled laborers, and one third professional/management and clerical/support personnel.

The plant support requirements including energy and water requirements already stated in Section 4.3 are summarized in Table 4.6.

TABLE 4.6

PLANT RESOURCE REQUIREMENTS

Item	Quantity
Land	80 hectares, 200 Acres
Manpower	500 Persons
Water	12.6 m^3/min, 3300 gpm
Energy	
Coal	2140 mtpd, 2350 tpd
Electricity	23.5 MW

4.5 WASTE TREATMENT

The types of waste treatment which could rationally be carried out on the wastes from a process plant were described in Section 3.12. In this section, the impact of treatment in terms of changes in the material and energy balances for the reduction/ammonia leach process are identified. These are presented on Table 4.7.

The first two treatment methods shown in Table 4.7 could be relatively easily accomplished, if required. The only substantial material supply impact on the base case (no treatment) would be a requirement for 810 mtpy (900 tpy) of 37 percent hydrochloric acid. However, if the wastes were to be dried as in the third treatment method the total coal

TABLE 4.7

WASTE TREATMENT IMPACT ON PLANT REQUIREMENTS

Materials/Services Required	Base Case		Treatment Method					
	pH Adjustment Only		Precipitate Toxic Elements Only		Precipitate Toxic Elements and Wash Solids		Precipitate Toxic Elements, Wash, and Dry Solids	
			ADDITIONAL MATERIALS/SERVICES REQUIRED					
Coal, mtpy x 10^3 (tpy x 10^3)	706	(775)			39	(43)	380	(420)
Lime, mtpy x 10^3 (tpy x 10^3)	8.4	(9.3)	8.7	(9.7)	8.7	(9.7)	8.7	(9.7)
Limestone, mtpy x 10^3 (tpy x 10^3)	24.0	(26.4)			1.4	(1.5)	12.8	(14.2)
Sorbent, mtpy x 10^3 (tpy x 10^3)		0			1.8	(2)	1.8	(2)
HCl (37%) mtpy (tpy)		0			810	(900)	810	(900)
Flocculants, mtpy x 10^3 (tpy x 10^3)	0.9	(1)			0.9	(1)	0.9	(1)
Water, m^3/yr x 10^6 (gpy x 10^6)	6.0	(1580)			0.4	(114)	0.5	(130)
Power, kWh x 10^6	188		0.4		15.8		19	
Wastes Produced			ADDITIONAL WASTES PRODUCED					
Stacked gases m^3/min x 10^3 (scfm x 10^3)	19.6	(705)			0.76	(27)	15.5	(547)
Cooling tower evaporation, m^3/min x 10^3 (scfm x 10^3)	2.8	(100)			0.9	(32)	1.1	(37)
Solid wastes, mtpy x 10^3 (tpy x 10^3)	2540	(2820)	13.7	(15.4)	18.9	(21)	61.5	(68.3)
Liquid wastes, m^3/yr x 10^6 (gpy x 10^6)	3.4	(900)			0.06	(15.2)	0.11	(29)

requirement for the plant would increase by more than 60 percent. This would effectively reduce the profit margin (ROI) by as much as 25 percent.

4.6 ACCIDENTAL RELEASE POTENTIAL

The inventory of potentially hazardous solids, liquids and gases which would be stored at the plant site or are "in-process" for the reduction/ammonia leach process are summarized in Table 4.8.

TABLE 4.8

INVENTORY OF POTENTIALLY HAZARDOUS SUBSTANCES

Total Liquid	91,000 tonnes	(100,000 Tons)
+ Solids	27,000 tonnes	(30,000 Tons)
Sulfuric Acid (Dilute)	18,000 tonnes	(20,000 Tons)
Ammonia	180-360 tonnes	(200-400 Tons)
Chlorine	23 tonnes	(25 Tons)
Hydrogen Sulfide	270-460 tonnes	(300-500 Tons)
Fuels	95,000 tonnes	(104,000 Tons)

The quantities of materials listed in Table 4.8 are nominal by industry standards. Similar quantities of ammonia, for instance, would be stored in farming areas for use as fertilizer and similar quantities of chlorine would be stored in large municipal water treatment plants. Comparable situations could be cited for most of the other potentially hazardous substances in inventory. Therefore, the process plant is typical of literally hundreds of existing facilities in terms of the types and quantities of potentially hazardous substances on hand.

The hazards from accidental release of the items inventoried for this process are summarized in Table 4.9. The rates of exposure, 10^{-7} per year, are extremely low and represent a probability of a release from one plant only once every 10 million years. There is a 1000 times greater risk that a person would be killed in an automobile accident in the U.S. than that one of these plants would release dangerous amounts of any hazardous liquid or gas.

Essentially large liquid releases are of little potential threat outside of the plant site, since internal holding ponds, dikes and the like would prevent liquids from escaping. Gases, however, could escape from the plant site if a major rupture or explosion occurred. Therefore, they are of more concern. The estimated probability of 10^{-7} for exposure at any given location within radii given in Table 4.9 has been explained previously. By comparison this is the same magnitude of safety margin required of the radiological system of a nuclear power plant which is designed to the highest achievable level of safety. The estimated exposure hazard is far less than the exposure risk of anyone within approximately the same radius from a large water treatment plant, railroad, or other facility where these gases are stored.

TABLE 4.9

HAZARDS SUMMARY

Large Liquid Releases - 10^{-7} Per Year

Large Gas Releases - 10^{-7} Per Year

Ammonia - 500 mg/l (or ppm) (level of concern)
to 13 km (8 Miles)

Hydrogen Sulfide - 1000 mg/l (or ppm) (fatal dose)
to 6 km (3.7 Miles)
50 mg/l (or ppm) (level of concern)
to 18 km (11 Miles)

Chlorine - 1000 mg/l (or ppm) (fatal dose)
to 3 km (1.9 Miles)
50 mg/l (or ppm) (level of concern)
to 9 km (5.6 Miles)

4.7 NOISE ASSESSMENT

The basis upon which this noise assessment was developed is discussed in Section 3.14. The noise level at the plant boundary is estimated at between 56 and 66 dBA. This noise level is shown graphically on Figure 4.3. This level corresponds approximately with the noise that would be generated near a freeway from auto traffic. Since a process plant would most likely be located in an already industrialized area or in a remote area, the noise impact would by any standard be negligible.

TYPICAL A-WEIGHTED SOUND LEVELS

At a Given Distance From Noise Source	Decibels RE: 20 N/m^2	Environmental
	140	
50 HP SIREN (100 FT)		
	130	
JET TAKEOFF (200 FT)		
	120	
RIVETING MACHINE CUTOFF SAW	110	CASTING SHAKEOUT AREA
PNEUMATIC PEEN HAMMER	100	ELECTRIC FURNACE AREA
TEXTILE WEAVING PLANT SUBWAY TRAIN (20 FT)	90	BOILER ROOM PRINTING PRESS PLANT
PNEUMATIC DRILL (50FT)		
	80	TABULATING ROOM INSIDE SPORT CAR (50 MPH)
FREIGHT TRAIN (100 FT) VACUUM CLEANER (10 FT) SPEECH (1 FT)	70	
REDUCTION/AMMONIA LEACH PROCESS	60	NEAR FREEWAY (AUTO TRAFFIC) LARGE STORE ACCOUNTING OFFICE
LARGE TRANSFORMER (200 FT)		PRIVATE BUSINESS OFFICE
	50	LIGHT TRAFFIC (100 FT) AVERAGE RESIDENCE
	40	MIN LEVELS RESIDENTIAL AREAS IN CHICAGO AT NIGHT
SOFT WHISPER (5 FT)		
	30	STUDIO (SPEECH)
	20	STUDIO FOR SOUND PICTURES
	10	
THRESHOLD OF HEARING YOUTHS 1000-4000 Hz	0	

FIGURE 4.3 ESTIMATED NOISE LEVEL AT PLANT BOUNDARY

5.0 CUPRION/AMMONIA LEACH PROCESS

5.1 INTRODUCTION

The cuprion/ammonia leach process would recover copper, nickel and cobalt from nodules by employing a reduction/ammoniacal leach. The cuprion process is a variation of the reduction/ammonia leach process with the essential difference being an initial low temperature hydrometallurgical reduction of manganese dioxide instead of a high temperature reduction. As a result, the cuprion process consumes less energy than the previously described reduction/ammonia leach process.

This process is illustrated by a simplified block diagram on Figure 5.1. Briefly the process consists of ore grinding and drying followed by a reduction-leach step. The copper, nickel and cobalt are then liberated in an ammoniacal/ammonium carbonate leach. Carbon monoxide is used to regenerate the cuprous ion which reduces manganese dioxide. Copper and nickel are coextracted by liquid ion exchange reagents and selectively stripped and recovered as electrowon cathodes. Cobalt is recovered from the raffinate by precipitation with hydrogen sulfide and is recovered from the sulfide precipitate by selective leaching and hydrogen reduction along with some nickel, zinc and copper. The metal-free raffinate is steam stripped to recover a high strength ammonia solution for recycle to the reduction step. The stripped raffinate is then recycled together with ammonia and ammonium carbonate recovered by steam stripping leach tailings, to the tailings wash step.

In this chapter the essential aspects of this process are summarized. This includes a more detailed description of the process; a summary of the plant inputs and outputs, plant support requirements; a summary of waste treatment alternatives and their impacts on material and energy balances; an accidental release analysis; and an assessment of the noise generated by the plant. A detailed description of this process is included in Volume III.

5.2 PROCESS DESCRIPTION

An outline of the cuprion process is shown in Figure 5.2. The first step in this process is ore grinding and drying followed by a low temperature (50°C, 122°F) hydrometallurgical reduction of manganese dioxide, the major mineral in nodules, to manganese carbonate by a carbon monoxide rich gas. The effect of this reduction is to disrupt the mineral structure and release the contained metals. The metals are removed from the reduced nodules by dissolution into a strong aqueous solution of ammonia and carbon dioxide at low temperature and pressure.

The metal-bearing solution decanted from the nodules is subjected to a series of purification steps, in which it is contacted with an organic medium which selectively and separately removes the copper and

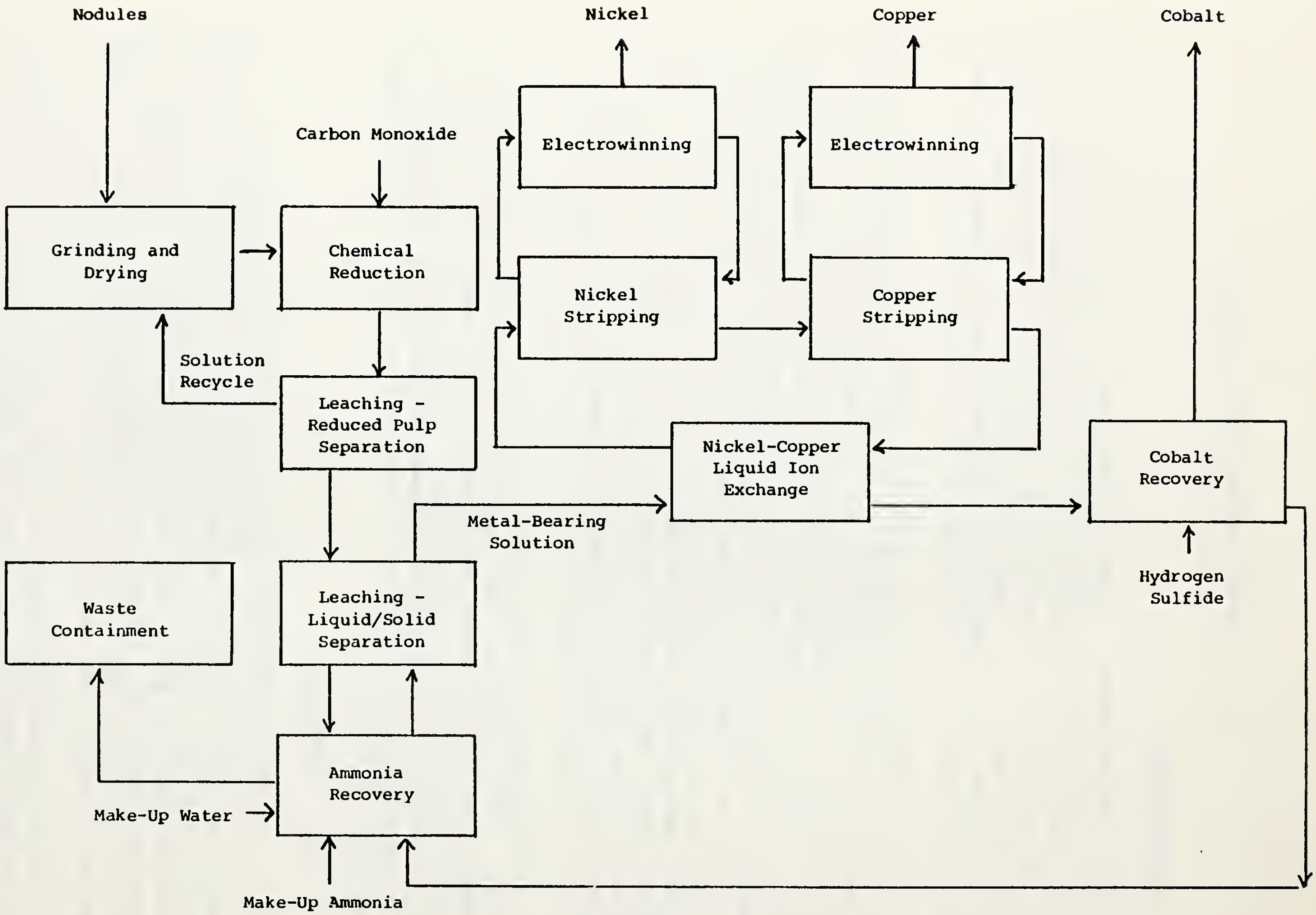

FIGURE 5.1 CUPRION AMMONIACAL LEACH PROCESS

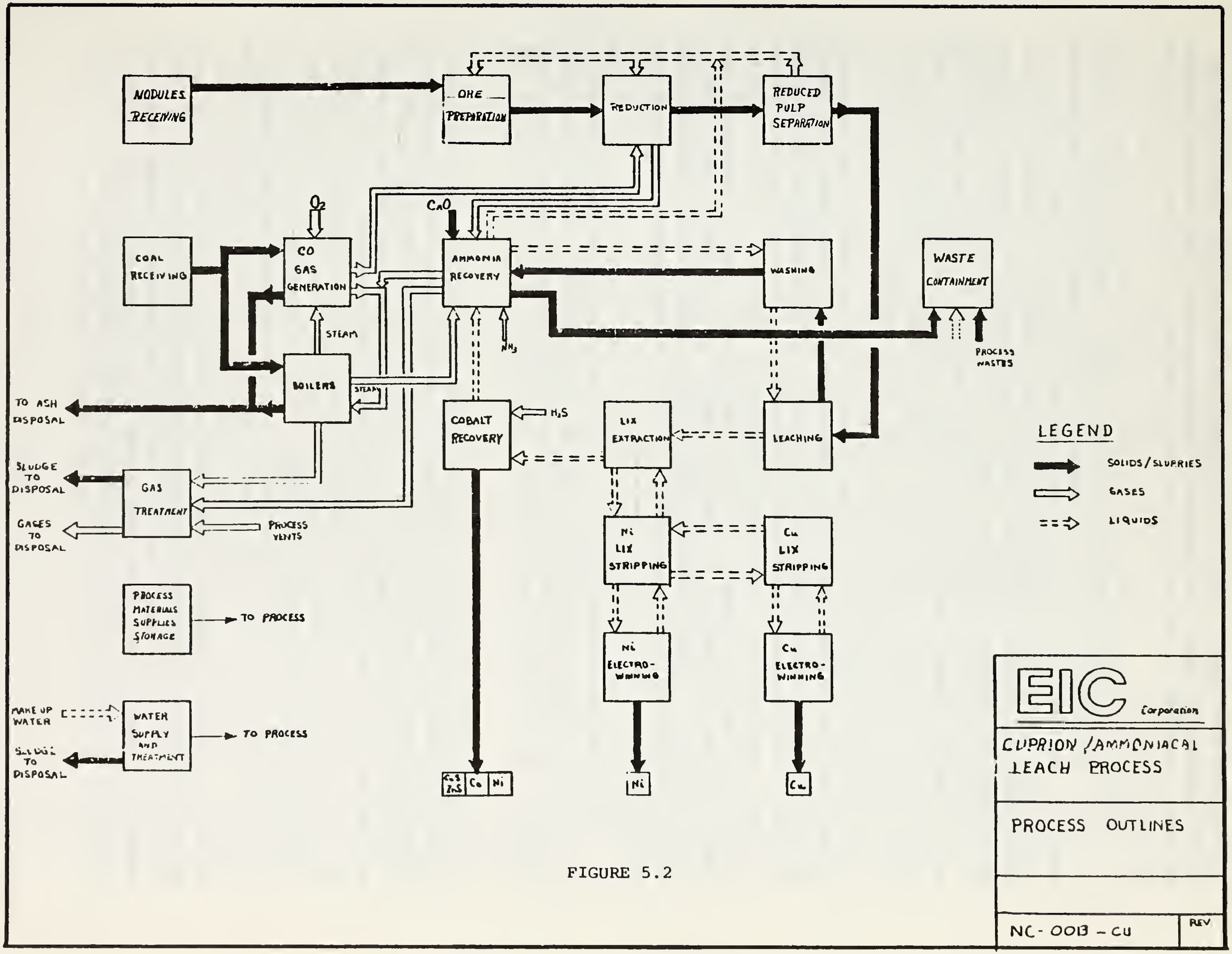
NODULES RECEIVING
ORE PREPARATION
REDUCTION
REDUCED PULP SEPARATION
COAL RECEIVING
O_2
CO GAS GENERATION
CaO
AMMONIA RECOVERY
WASHING
WASTE CONTAINMENT
PROCESS WASTES
STEAM
NH_3
BOILERS
STEAM
TO ASH DISPOSAL
COBALT RECOVERY
H_2S
LIX EXTRACTION
LEACHING
SLUDGE TO DISPOSAL
GAS TREATMENT
GASES TO DISPOSAL
PROCESS VENTS
Ni LIX STRIPPING
Cu LIX STRIPPING
PROCESS MATERIALS SUPPLIES STORAGE
TO PROCESS
Ni ELECTRO-WINNING
Cu ELECTRO-WINNING
MAKE UP WATER
WATER SUPPLY AND TREATMENT
TO PROCESS
SLUDGE TO DISPOSAL
CuS ZnS
Co
Ni
Ni
Cu
LEGEND
SOLIDS/SLURRIES
GASES
LIQUIDS
EIC Corporation
CUPRION/AMMONIACAL LEACH PROCESS
PROCESS OUTLINES
NC-003 -CU
REV

FIGURE 5.2

nickel from the organic fluid, and transferred to acid aqueous solutions, which accumulate copper sulfate and nickel sulfate. The metal products, cathode copper and nickel, are produced from these solutions by electrodeposition.

Cobalt is then recovered from the aqueous ammonia/carbon dioxide solution by contacting it with hydrogen sulfide, which precipitates the insoluble sulfides of cobalt as well as small amounts of the sulfides of copper, nickel, zinc, and other metals not removed in previous steps. The solids are removed from the aqueous ammonia/carbon dioxide solution and contacted with air and hot (100°C, 212°F) sulfuric acid to selectively redissolve the cobalt and the small amount of nickel present. The undissolved sulfides are sold as minor products, and the cobalt and nickel are recovered from solution in powder form by selective reduction with hydrogen at high pressure (34 atm) and temperature (185°C, 365°F).

The reduced nodules residue, from which the major portion (98 percent) of the soluble metals has been removed, is contacted with steam (at 120°C, 248°F, 2 atm pressure) to remove residual ammonia and carbon dioxide. The aqueous ammonia/carbon dioxide mixture, from which cobalt had been removed, is also steam stripped to recover a high strength ammonia solution for recycle to the reduction step and to provide fresh wash solution for recycle to extract more metal values from freshly reduced nodules. The steam-stripped nodule residues are combined with smaller amounts of other process solid and liquid wastes and sent to containment.

Plant services include facilities for generating the carbon monoxide gas used in nodule reduction, raising the necessary steam and power required for process use, supplying the make-up water and cooling required, and providing for materials handling for process materials and supplies.

The hydrometallurgical reduction of nodules in an ammoniacal ammonium carbonate solution has been disclosed in the patent literature. While this approach differs from the pyrometallurgical reductions used in the well known Caron process, the basic outline for the Cuprion process is similar. The metal separation and purification scheme, however, is specific to nodules and is complicated by the chemical similarity of copper, nickel, and cobalt. Separation and purification of copper and nickel by selective extraction with organic compounds (liquid ion exchange reagents) is currently practiced in the extractive metallurgy of copper and nickel. However, in these cases the aqueous solutions contain primarily one metal, the others being treated as impurities, not products. Cobalt recovery from precipitated mixtures of nickel and cobalt sulfides derived from laterities is also currently practiced. The details of the procedures used to purify the leach solutions prior to reduction, however, would differ somewhat from those used for nodules because of the differences in amount and content of impurities.

The requirement that the reduction and wash steps be carried out with solutions of differing ammonia and ammonium carbonate compositions, however, requires an additional step, raffinate stripping, not used in the pyrometallurgical reduction/ammonia leach process. The generation of carbon monoxide gas from coal or oil for the reduction of nodules and all other plant services represent the utilization of known technology essentially without adaptation.

The basic process configuration proposed, then, is a modified version of the well established Caron process for recovering nickel from laterites. The major difference is the reduction and metals separation and purification steps, and represents an extension of elements of existing technology to a new application in nodules processing.

A major alternative to the proposed process configuration involves the high temperature reduction of the nodules using carbon monoxide rich producer gas. This option was described in Chapter 4.0. Other variations in the process are possible, particularly with respect to the specific metals separation and purification schemes used. However, they would probably have only minor impact on overall inputs and outputs.

Alternative approaches to the recovery of ammonia/ammonium carbonate solutions of differing strengths for recycle within the process could, however, have major impacts on the plant energy balance. Savings up to one third in steam generation (25 percent in coal consumption) might be possible at the expense of purchasing up to 10 MW of power from outside sources. In addition, it has been assumed that a major by-product of carbon monoxide production, 0.65×10^6 m^3/day (23×10^6 SCFD) of hydrogen, would be burned. If markets were available it could be sold at the cost of making up an additional 300 mtpd (330 tpd) coal.

5.3 PLANT INPUTS AND OUTPUTS

The major items which comprise the material and energy balances for the cuprion/ammonia leach process are summarized in Table 5.1. Included are production rates for the saleable products, consumption rates for major materials and supplies, raw materials requirements and a breakdown of the amounts of solid, liquid and gaseous wastes and the requirements for fuels and purchased power.

The distribution of services required within the plant is summarized on Table 5.2. The services include process power, process steam, cooling water and process water.

The composition of the output streams which constitute process wastes is summarized on Tables 5.3 and 5.4 for the solid and liquid and gaseous wastes, respectively. These compositions were derived from the overall plant material balance and are presented for only the major materials in the process. Where trace amounts of a material are indicated, it has been assumed that previous removal steps will have reduced it to a level which is either accepted for discharge directly or it is present in amounts too low to quantify within the accuracy of the methods used in this study.

TABLE 5.1

MAJOR PLANT INPUTS AND OUTPUTS

	MAJOR INPUTS	
Nodules	3.7×10^6 mtpy	4.1×10^6 tpy
Coal	628×10^3 mtpy	690×10^3 tpy
Water	7.9×10^6 m^3/yr	2090×10^6 gpy
Gases	7.7×10^3 mtpy	8.5×10^3 tpy
Liquids	4.9×10^3 m^3/yr	1.3×10^6 gpy
Solids	3.1×10^3 mtpy	3.5×10^3 tpy
Purchased Power	0	0
	MAJOR OUTPUTS	
Solid Wastes	3.27×10^6 mtpy	3.59×10^6 tpy
Liquid Wastes	4.28×10^6 m^3/yr	1130×10^6 gpy
Stacked Offgases	7.8×10^3 m^3/min	275×10^3 scfm
Low Level Emissions	1.8×10^3 m^3/min	65×10^3 scfm
Copper	27×10^3 mtpy	30×10^3 tpy
Nickel	33×10^3 mtpy	36×10^3 tpy
Cobalt	3.9×10^3 mtpy	4.3×10^3 tpy

A summary of the flows and distributions of potentially toxic elements for the reduction/ammonia leach process is presented in Table 5.5. The discussion in Section 4.3 is applicable to the Cuprion process also. Although a somewhat higher percentage of potentially toxic elements would report to the tailings in the Cuprion process, the ultimate result is the same. That is, the tailings may be safely stored in a lined tailings disposal facility.

TABLE 5.2

SERVICES PROFILE

	Process Power	Process Steam		Cooling Water		Process Water	
	kW	kg/hr x 10^3	pph x 10^3	m^3/min	gpm	m^3/min	gpm
Ore Preparation	3,200	-	-	-	-	-	-
Reduction/Leaching	4,000	-	-	163	43,000	-	-
Leaching	700	-	-	-	-	-	-
Tailings Washing	450	-	-	-	-	0.03	8
Liquid Ion Exchange	900	12.9	28.4	4.4	1,150	0.12	32.6
Copper Electrowinning	9,500	7.5	16.5	3.4	900	0.06	15
Nickel Electrowinning	15,800	4.3	9.5	0.2	50	0.09	25
Cobalt Recovery	900	28.4	62.4	10.2	2,700	0.06	17
Ammonia Recovery	1,150	438.0	963	272	71,700	2.3	600
Materials Handling	1,000	-	-	-	-	0.08	20
Services & General Plant Use	13,900	46.4(1)	102.2(1)	30.3	8,000	14.1	3,720
	(51,500)(2)						
TOTAL	0	538(3)	1182(3)	483(4)	127,500(4)	16.8(5)	4,400(5)

(1) 27 x 10^6 kcal/hr (108 x 10^6 Btu/hr) to boiler feed washing heating.

(2) Generated internally.

(3) 468 x 10^3 kg/hr (1030 x 10^3 pph) used in power generation.

(4) 288 x 10^6 kcal/hr (1150 x 10^6 Btu/hr) non consumptive use.

(5) Consumptive use.

TABLE 5.3

CHARACTERIZATION OF SOLID AND LIQUID WASTES

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHING TAILS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	GASIFICA-TION ASH (slag)	COMBUS-TION ASH	GAS SCRUBBER SOLIDS
Solid Flows	mtpd	2.2	0.11	0.11	9,500	58	10	110	90	65
	tpd	2.4	0.12	0.12	10,500	64	11	120	100	72
Liquid Flows	m^3/hr				430	15	1.2	78		10
	gpm				1930	65	5.3	345		45
Temperature	$^oC/^oF$	25/77	40/104	25/77	50/122	50/122	25/77	30/86	90/194	55/131
Constituents:		. Lead . Lead Sulfate . Manganese Dioxide . Etc.	. UNK	. Carbon	. Manganese Dioxide . Manganese Oxide . Manganese Carbonate . Iron Hydroxide . Clays . Ammonia . Carbon Dioxide . Copper . Zinc . Cobalt . Nickel . Molybdenum . Sea Salt	. Gypsum . Silica . Aluminum Oxide . Nickel . Cobalt . Sea Salt . Magnesium . Sodium . Boric Acid	. Limestone . Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Calcium Sulfite . Calcium Sulfate . Silica . Aluminum Oxide . Manganese Dioxide . Manganese Carbonate . Magnesium
Chemical Characteristics:		A			A, C	A, C, D	B, D	A, B	A, B	A, B, C, D
Physical Characteristics:		D			A, B	B	B	C		B

KEY:

CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS	
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 5.4

COMPOSITION OF GASEOUS EFFLUENT STREAMS

STREAM		DUST CONTROL EXHAUSTS	COPPER TANK HOUSE EXHAUST(1)	NICKEL TANK HOUSE EXHAUST(1)	LEACH REACTOR VENT	AMMONIA SCRUBBER VENT	STACKED GASES	ACID GASES	HYDROGEN TO BOILER	REDUCTION OFFGAS
Total Flow	m^3/min	1,415	130(1)	146(1)	150	337	7,785	108	459	70
	scfm	50,000	4,600(1)	5,150(1)	5,300	11,900	275,000	3,800	16,200	2,500
Temp.,	°C	25	50	50	40	40	145	90	50	50
	°F	77	122	122	104	104	293	194	122	122
Press., Atmospheres		1	1	1	1	1.1	1	1.1	1.1	1.1
% Oxygen		21	7	7.5	16	20	4.2			
Nitrogen		79			77	77	71.1	1.3		0.3
Ammonia						TR	TR			17.3
Carbon Monoxide							TR	13	1	34.7
Carbon Dioxide							11.6	78.2		TR
Hydrogen				0.5				3.9	98	41.2
Water			93	92	7	3	13.1	1	1	6.5
Hydrogen Sulfide, Sulfur Dioxide							2.6			

Cell exhaust only, excluding building ventilation

TABLE 5.5

DISTRIBUTION OF POTENTIALLY TOXIC ELEMENTS

Element	Input Rate To Plant		Distribution As Percent Reporting To	
	kg/day	(lbs/day)	Waste	Product
Barium	34,500	76,000	100.0	0
Lanthanum	14,100	31,000	100.0	0
Vanadium	3,450	7,600	99.4	0.6
Chromium	86	190	99.0	1.0
Silver	27	60	13.0	87.0
Cadmium	172	380	20.0	80.0
Arsenic	436	960	73.0	27.0
Antimony	263	580	91.0	9.0
Thallium	1,730	3,800	76.0	24.0
Lead	4,360	9,600	93.5	6.5

5.4 PLANT RESOURCE REQUIREMENTS

It is estimated that the total plant facility, including processing and support facilities but excluding long-term waste containment areas, will require approximately 80 hectares (200 acres) of land. Within the main processing area, the plant layout will involve equipment densities which are typical for the chemical processing industry. Separate processing buildings would be provided for the liquid ion exchange operation and for copper and nickel electrowinning and cobalt recovery. Nodule reduction, ammonia recovery, and coal gasification would be open-air installations. A boiler house/power house and banks of cooling towers would be located adjacent to the chemical process areas. Offices, laboratories, maintenance shops, warehouses, control houses, change house/cafeteria, and parking area would also be located close to the main processing area. While the aforementioned facilities would require approximately 8 to 20 hectares (20 to 50 acres) of land, the plant layout is dominated by the requirement to provide materials storage areas and for the thickeners in the leaching and washing section. Approximately 10 hectares (25 acres) would be required for the thickeners, nodule storage, and decant ponds. The coal, lime, and limestone storage area and a plant runoff and emergency waste-storage area would require at least 20 hectares (50 acres), including margins of relatively flat terrain. No unusually tall structures would be required in the process areas, except perhaps for the main stack, which could be several hundred feet high, depending on local meteorological conditions.

The materials movement in and out of the plant is significant, even excluding raw nodules, waste products, and oxygen. In excess of 2000 mtpd (2200 tpd) of fuels and process materials are brought in, and 200 mtpd (220 tpd) of products are shipped out. Thus, the transportation network supporting plant operations must include highway and rail connections capable of supporting considerable traffic. The coal, lime, limestone, ammonia, hydrogen sulfide, and sulfuric acid would be delivered by rail, and copper and nickel would be shipped by rail. Most other materials and supplies would be trucked, except that 600 mtpd (660 tpd) of oxygen would probably be purchased from an adjacent or nearby facility and delivered to the plant by pipeline.

Plant operations will be on a 3-shift, 365-day-per-year basis. It is estimated that approximately 500 people will be employed in the facility, including operating and maintenance labor, supervision, and plant general and administrative personnel. The mix of skill levels would be typical of a chemical processing plant, with approximately one-third being skilled tradesmen and lead operators, one-third unskilled laborers, and one-third professional/management and clerical/support personnel.

The plant support requirements including energy and water requirements already stated in Section 5.3 are summarized in Table 5.6.

TABLE 5.6

PLANT RESOURCE REQUIREMENTS

Item	Quantity
Land	80 hectares, 200 acres
Manpower	500 Persons
Water	16.7 m^3/min, 4400 gpm
Energy	
Coal	1910 mtpd, 2100 tpd
Electricity	0

5.5 WASTE TREATMENT

The types of waste treatment which could rationally be carried out on the wastes from a process plant were described in Section 3.12. In this section the impact of treatment in terms of changes in the material and energy balances for the cuprion process are identified. These are presented in Table 5.7.

5.6 ACCIDENTAL RELEASE POTENTIAL

The inventory of potentially hazardous solids, liquids and gases which would be stored at the plant site or are "in-process" for the cuprion process are summarized in Table 5.8.

TABLE 5.7

WASTE TREATMENT IMPACT ON PLANT REQUIREMENTS

	Base Case		Treatment Method					
Materials/Services Required	pH Adjustment Only		Precipitate Toxic Elements Only		Precipitate Toxic Elements and Wash Solids		Precipitate Toxic Elements, Wash, and Dry Solids	
			ADDITIONAL MATERIALS/SERVICES REQUIRED					
Coal, mtpy x 10^3 (tpy x 10^3)	628	(690)			34	(37)	502	(551.5)
Lime, mtpy x 10^3 (tpy x 10^3)	9.0	(9.9)	9.6	(10.6)	9.6	(10.6)	9.6	(10.6)
Limestone, mtpy x 10^3 (tpy x 10^3)	21.2	(23.3)			0.9	(1.3)	17	(18.7)
Sorbent, mtpy x 10^3 (tpy x 10^3)		0			1.8	(2)	1.8	(2)
HCl (37%), mtpy (tpy)		0			820	(900)	820	(900)
Flocculants, mtpy x 10^3 (tpy x 10^3)	0.9	(1)			0.9	(1)	0.9	(1)
Water, m^3/yr x 10^6 (gpy x 10^6)	7.9	(2090)			0.4	(109)	0.5	(128)
Power, kWh x 10^6		0	0.4		7.9		36	
Wastes Produced			ADDITIONAL WASTES PRODUCED					
Stacked gases, m^3/min x 10^3 (scfm x 10^3)	7.8	(275)			0.65	(23)	20.8	(733)
Cooling tower evaporation, m^3/min x 10^3 (scfm x 10^3)		0			0.88	(31)	1.0	(35.6)
Solid wastes, mtpy x 10^3 (tpy x 10^3)	3270	(3590)	10.5	(11.5)	14.6	(16.1)	73.5	(80.8)
Liquid wastes, m^3/yr x 10^6 (gpy x 10^6)	4.3	(1130)			0.06	(14.7)	0.11	(29)

TABLE 5.8

INVENTORY OF POTENTIALLY HAZARDOUS SUBSTANCES

Total Liquid	91,000 tonnes	(100,000 Tons)
+ Solids	27,000 tonnes	(30,000 Tons)
Sulfuric Acid (Dilute)	91,000 tonnes	(100,000 Tons)
Ammonia	450 tonnes	(500 Tons)
Chlorine	14 tonnes	(15 Tons)
Hydrogen Sulfide	450 tonnes	(500 Tons)
Fuels	91,000 tonnes	(100,000 Tons)

The hazards summary for accidental release of the items inventoried for this process are summarized in Table 5.9.

TABLE 5.9

HAZARDS SUMMARY

Large Liquid Releases -	10^{-7} Per Year
Large Gas Releases -	10^{-7} Per Year
Ammonia -	500 mg/l (or ppm) (level of concern) to 13 km (8 Miles)
Hydrogen Sulfide -	1000 mg/l (or ppm) (fatal dose) to 6 km (3.7 Miles) 50 mg/l (or ppm) (level of concern) to 18 km (11 Miles)
Chlorine -	1000 mg/l (or ppm) (fatal dose) to 3 km (1.9 Miles) 50 mg/l (or ppm) (level of concern) to 9 km (5.6 Miles)

The probability of major pollutant releases are assessed as equivalent to those for an ammonia process plant; 10^{-7} per year for liquid releases such as the kerosene, slurry, or acid solutions of salts and 10^{-7} per year for major gas releases of ammonia and hydrogen sulfide.

5.7 NOISE ASSESSMENT

The basis upon which this noise assessment was developed is discussed in Section 3.14. The noise level at the plant boundary is estimated at between 51 and 61 dBA. This noise level is shown graphically on Figure 5.3. This level corresponds approximately with the noise that would be generated in a large store accounting office.

TYPICAL A-WEIGHTED SOUND LEVELS

At a Given Distance From Noise Source	Decibels RE: 20 N/m^2	Environmental
	140	
50 HP SIREN (100 FT)		
	130	
JET TAKEOFF (200 FT)		
	120	
RIVETING MACHINE	110	CASTING SHAKEOUT AREA
CUTOFF SAW		
PNEUMATIC PEEN HAMMER	100	ELECTRIC FURNACE AREA
TEXTILE WEAVING PLANT		
SUBWAY TRAIN (20 FT)	90	BOILER ROOM
		PRINTING PRESS PLANT
PNEUMATIC DRILL (50FT)		
	80	TABULATING ROOM
		INSIDE SPORT CAR (50 MPH)
FREIGHT TRAIN (100 FT)		
VACUUM CLEANER (10 FT)	70	
SPEECH (1 FT)		
		NEAR FREEWAY (AUTO TRAFFIC)
	60	LARGE STORE
CUPRION PROCESS		ACCOUNTING OFFICE
LARGE TRANSFORMER (200 FT)		PRIVATE BUSINESS OFFICE
	50	LIGHT TRAFFIC (100 FT)
		AVERAGE RESIDENCE
		MIN LEVELS RESIDENTIAL AREAS
	40	IN CHICAGO AT NIGHT
SOFT WHISPER (5 FT)		
	30	STUDIO (SPEECH)
	20	STUDIO FOR SOUND PICTURES
	10	
THRESHOLD OF HEARING		
YOUTHS 1000-4000 Hz	0	

FIGURE 5.3 ESTIMATED NOISE LEVEL AT PLANT BOUNDARY

6.0 HIGH TEMPERATURE SULFURIC ACID PROCESS

6.1 INTRODUCTION

Nickel, copper and cobalt can be recovered from nodules by a "pressure cooking" process at high temperatures and pressures in an aqueous sulfuric acid solution. This process is basically similar to the process used to treat nickel laterite ores at Moa Bay, Cuba.

This process is illustrated by a simplified block diagram on Figure 6.1. Briefly the process consists of wet grinding of the nodules followed by selective leaching at high temperature using a strong sulfuric acid solution. After separation of the leaching residue and metalliferous solution by washing, the copper and nickel are selectively extracted and recovered as electrolytic cathodes. Cobalt is recovered from the raffinate by precipitation with hydrogen sulfide and is recovered from the sulfide precipitate by selective leaching and hydrogen reduction, along with some nickel, copper, and zinc. The metal free raffinate liquor - basically water - is recycled to the washing process. Ammonia used in the process is recovered and recycled to the process for use in pH control.

In subsequent paragraphs of this chapter a summary of the essential aspects of this process are described. This includes a description of the process; a summary of the plant inputs and outputs, plant support requirements, waste treatment alternatives and their impacts on material and energy balances, accidental release of hazardous substance potential and noise generated by the plant. A detailed description of this process is included in Volume III.

6.2 PROCESS DESCRIPTION

An outline of the high temperature sulfuric acid process is shown in Figure 6.2. The first step in this process is wet grinding of the nodules followed by a high temperature (470°C, 878°F) and pressure (35 atm) "cooking" of the ground nodules. Nearly the entire quantity of major minerals of value in the nodules become dissolved in the hot, strong (30 percent) sulfuric acid solution. After cooling, the nodule residue and solution are separated by decantation. Water that is used to wash the residue free of acid and metals is combined with the solution, and the residue is sent to a containment area.

The metal-bearing solution, which contains residual acid, passes to a pH-adjustment step to make the solution more suitable for further processing. The solution is then contacted with an organic medium to selectively remove the copper. The extracted nickel and copper are separately and selectively removed from their respective organic fluids and transferred to acid aqueous solutions, which accumulate nickel and

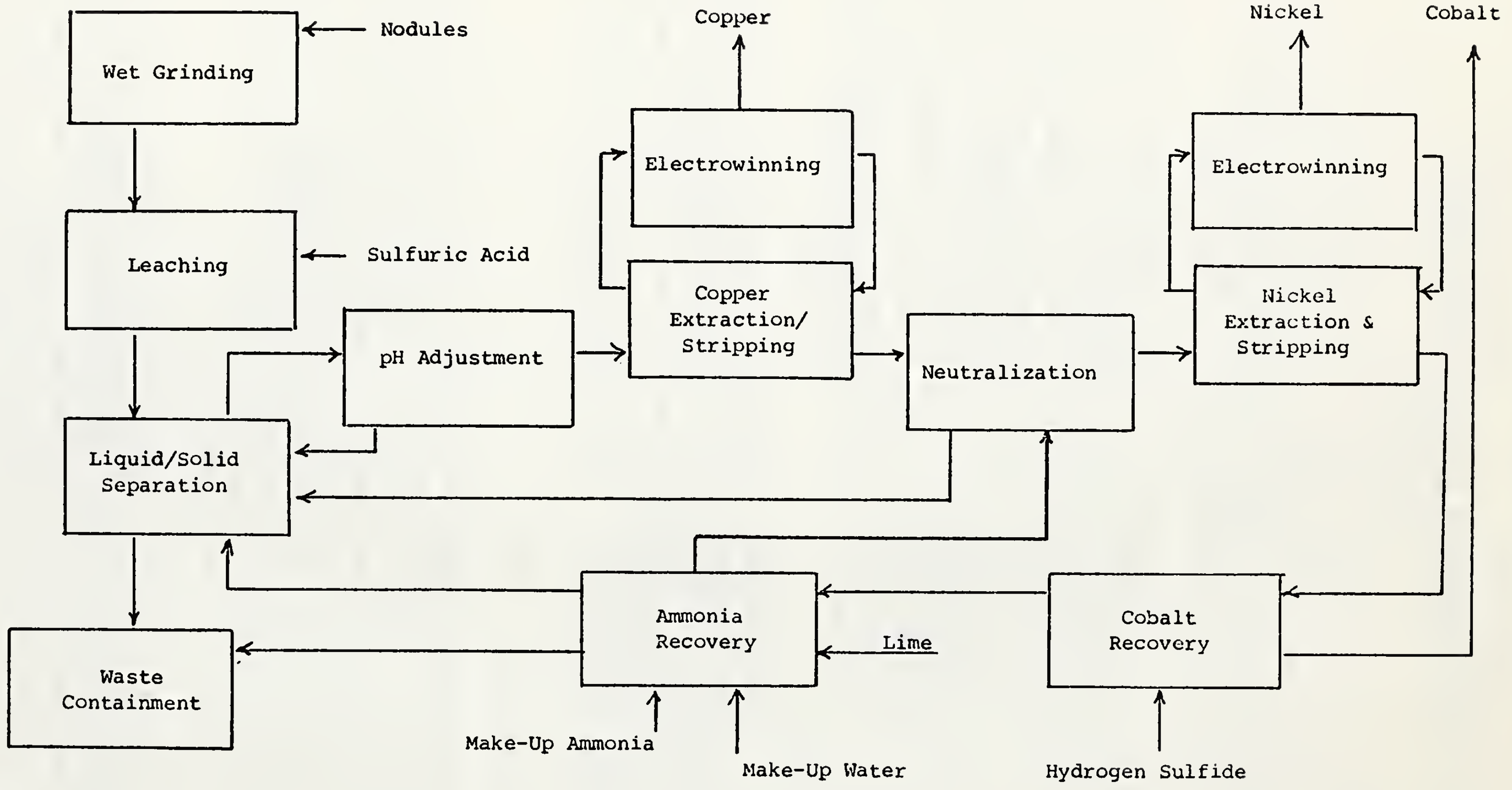

FIGURE 6.1 HIGH-TEMPERATURE SULFURIC ACID PROCESS

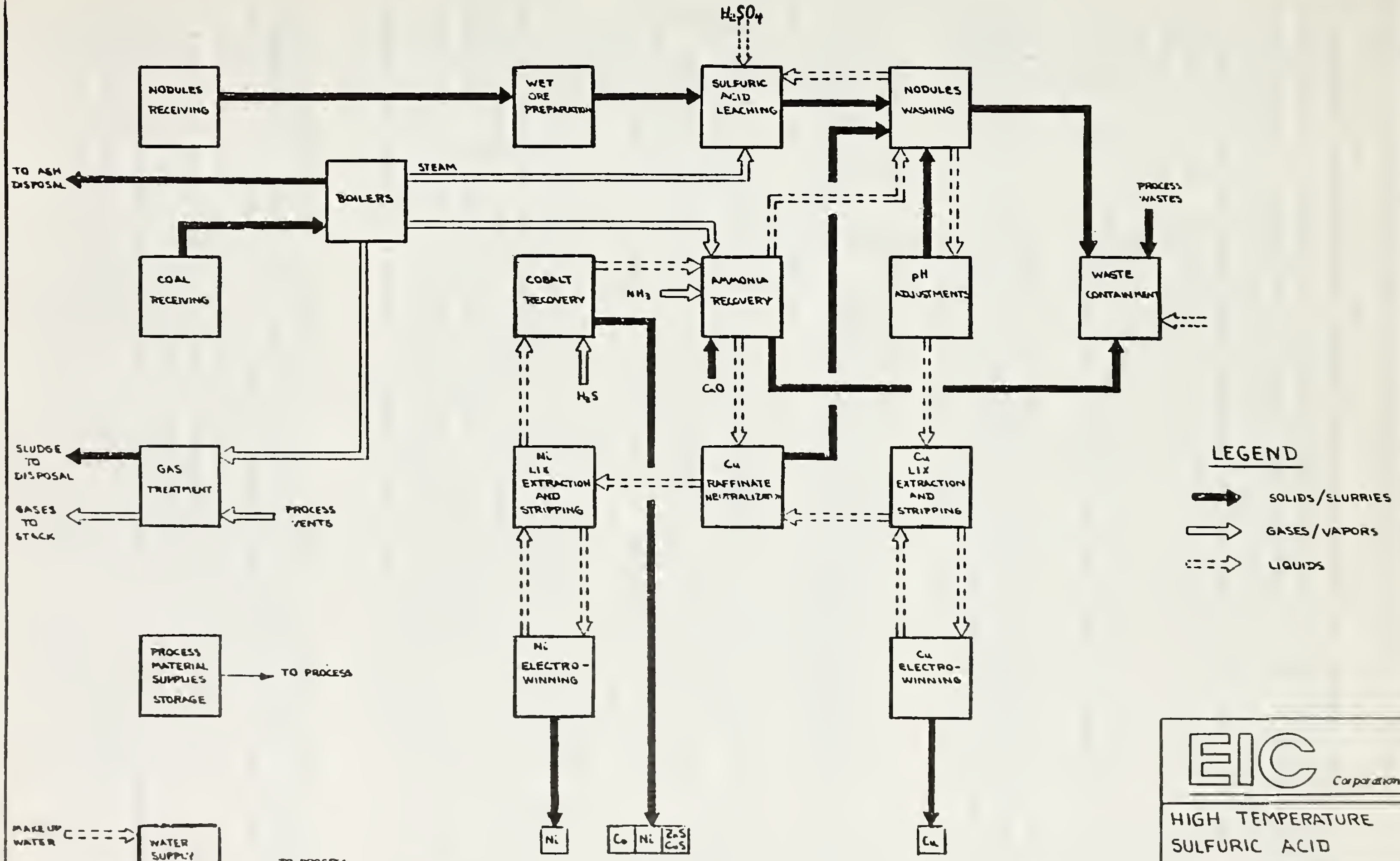

FIGURE 6.2

EIC Corporation

HIGH TEMPERATURE
SULFURIC ACID
LEACH PROCESS

PROCESS OUTLINE

DRAWING NO. NC-0015-SU
REV. 0

copper sulfate respectively. The metal products, cathode nickel and copper, are produced from these solutions by electrodeposition.

The cobalt constituent of the solution is then recovered by contacting with hydrogen sulfide, which causes insoluble sulfides of cobalt as well as small amounts of copper, nickel, zinc, and other metals not removed in previous steps to precipitate from solution. The solid residue is removed from solution and contacted with air and hot (100°C, 212°F) sulfuric acid to selectively redissolve the cobalt and the small amount of nickel present. The undissolved sulfides are sold as minor products, and the cobalt and nickel are recovered from solution in powder form by selective metal formation through use of hydrogen gas at high pressure (34 atm pressure) and temperature (185°C, 365°F).

The solution, depleted of copper, nickel and cobalt, is chemically treated to recover the ammonia introduced during the neutralization step. The recovered ammonia is recycled for use in the process, and the ammonia free solution is returned to wash freshly leached nodules.

Plant services include facilities for generating the necessary steam and part of the power required for process use, supplying the make-up water and cooling required, and providing for materials handling for process materials and supplies.

A major alternative to the proposed process configuration involves a low temperature, low pressure treatment of slurried nodules in acid solution. There are, however, major drawbacks, such as solubilization of an undesirable amount of iron that would need to be removed, longer treatment time, and lower recovery of nickel, copper and cobalt. A second alternative would involve the evaporation of metal-free ammonia solutions and crystallization of fertilizer grade ammonium sulfate for sale rather than recovery of ammonia to the process with disposal of gypsum. This alternative, while technically feasible, would need to be studied carefully in view of its overall economics in the metals production plant and for its impact on the local fertilizer market. Other variations in the process are possible, particularly with respect to the specific metals separation and purification schemes used. However, they would likely have only minor impact on overall process inputs and outputs.

Descriptions of high temperature and pressure acid treatment of nodules has had limited exposure in the literature, with most descriptions occurring in foreign patents and papers. A basically similar process for treatment of nickel laterite ores, however, has been used at Moa Bay, Cuba. This configuration proposed is an update using currently available technology of Moa Bay operations. The metal separation and purification scheme, however, is specific to nodules and is complicated by the chemical similarity of copper, nickel and cobalt. Separation and purification of copper and nickel by selective extraction with organic compounds (liquid ion exchange reagents) is currently practiced in the extractive metallurgy of nickel and copper. However, in these cases the aqueous solutions contain primarily one metal, the others being treated as impurities, not products. Cobalt recovery from precipitated mixtures of nickel and cobalt sulfides derived from laterites is also currently practiced. The details of the procedures used to purify the leach solutions prior to cobalt reduction, however, would differ somewhat from those used for nodules because of the differences in amount and content of impurities. The generation of steam and all other plant services represent the utilization of known technology essentially without adaptation.

The basic process configuration proposed, then, is a modification of the Moa Bay process for recovering nickel from laterites. The major difference is in the metals separation and purification steps, and represents an extension of methods of existing technology to a new application in nodules processing. The detailed design bases used in developing the process description are summarized in the criteria sheets in Volume III.

6.3 PLANT INPUTS AND OUTPUTS

The major items which comprise the material and energy balances for the high temperature sulfuric acid process are summarized in Table 6.1. Included are consumption rates for major materials and supplies, raw materials requirements and a breakdown of the amounts of solid, liquid and gaseous wastes and the requirements for fuels and purchased power.

The distribution of services required within the plant is summarized on Table 6.2. The services include process power, process steam, cooling water and process water.

The composition of the output streams which constitute process wastes is summarized on Tables 6.3 and 6.4 for the solid and liquid and gaseous wastes, respectively. These compositions were derived from the overall plant material balance and are presented for only the major materials in the process. Where trace amounts of a material are indicated, it has been assumed that previous removal steps will have reduced it to a level which is either acceptable for discharge directly or it is present in amounts too low to quantify within the accuracy of the methods used in this study.

A summary of the flows and distributions of potentially toxic elements for the high temperature sulfuric acid leach process is presented in Table 6.5. In this process large portions of all the toxic elements except barium, chromium and lead report to the products and are of no concern. The toxic elements reporting to the wastes are largely in the same chemical form as they were in raw nodules or are precipitated as inert compounds. Either way they would be safely disposed of in a tailings containment site.

TABLE 6.1

MAJOR PLANT INPUTS AND OUTPUTS

MAJOR INPUTS

Nodules	3.7×10^6 mtpy	4.1×10^6 tpy
Coal	328×10^3 mtpy	360×10^3 tpy
Water	5.38×10^6 m^3/yr	1.54×10^9 gpy
Sulfuric Acid	855×10^3 mtpy	940×10^3 tpy
Solids	2160 mtpy	2370 tpy
Liquids	0.51×10^6 m^3/yr	135×10^6 gpy
Gases	7.1×10^3 mtpy	7.8×10^3 tpy
Purchased Power	158.4×10^6 kwh	

MAJOR OUTPUTS

Solid Wastes	3.84×10^6 mtpy	4.22×10^6 tpy
Liquid Wastes	4.24×10^6 m^3/yr	1120×10^6 gpy
Stacked Offgases	6.94×10^3 m^3/min	245×10^3 scfm
Low Level Emissions	1.90×10^3 m^3/min	67×10^3 scfm
Cooling Tower Evaporation	5.93×10^3 m^3/min	213×10^3 scfm
Copper	29×10^3 mtpy	32×10^3 tpy
Nickel	34.8×10^3 mtpy	38.2×10^3 tpy
Cobalt	3.7×10^3 mtpy	4.1×10^3 tpy

6.4 PLANT RESOURCE REQUIREMENTS

It is estimated that the total plant facility including processing and support facilities, but excluding long term waste containment areas, will require approximately 73 hectares (180 acres) of land. Within the hydrometallurgical processing area, the plant layout will involve equipment densities which are typical for the chemical processing industry. Separate processing buildings would be provided for the liquid ion exchange operation and for copper and nickel electrowinning and cobalt recovery. Nodule grinding and leaching, pH adjustment and neutralization, and ammonia recovery would be outside installations. A boiler house/power house and banks of cooling towers would be located adjacent to the chemical process areas, and offices, laboratories, maintenance shops, warehouses, control houses, and a change house/cafeteria and parking area would also be located close to the main processing area. While the aforementioned facilities would require about 8 to 16 hectares (20-40 acres) of land, the plant layout is dominated by the requirement to provide for materials storage areas and for the thickeners in the washing section. Approximately 8 hectares (20 acres) would be required for the thickeners. The nodules storage and decant ponds, the coal and lime and limestone storage area, and a plant run off and emergency waste storage area would require at least 20 hectares (50 acres), including margins, of relatively flat terrain. No unusually tall structures would

TABLE 6.2

SERVICES PROFILE

	Process Power	Process Steam		Cooling Water		Process Water	
	kW	kg/hr x 10^3	pph x 10^3	m^3/min	gpm	m^3/min	gpm
Ore Preparation	2,900	-	-	-	-	-	-
Leaching	1,350	174(1)	383(1)	112	29,600	-	-
Tailings Washing	600	-	-	-	-	0.09	25
pH Adjustment	450	-	-	13	3,400	-	-
Copper Extraction/Stripping	300	2.0	4.5	1.9	500	-	-
Copper Electrowinning	10,000	3.9	8.5	-	-	0.08	20
Neutralization	700	-	-	-	-	-	-
Nickel Extraction/Stripping	600	5.9	13	1.9	500	0.08	20
Nickel Electrowinning	16,650	4.6	10.1	-	-	0.09	25
Cobalt Recovery	900	23.4	51.4	8	2,100	-	-
Ammonia Recovery	750	139	306	127	33,600	0.04	11
Materials Handling	1,050	-	-	-	-	-	-
Services	6,850	-	-	4.6	1,200	11.6	3,070
	(24,300)(2)	59(3)	130(3)				
TOTAL	18,800	318	700	269(4)	70,900(4)	12(5)	3,200(5)

(1) 37 x 10^3 kg/hr (81 x 10^3 lbs/hr) flashed steam exported for process use.

(2) Generated internally.

(3) Used internally in power generation.

(4) 160 x 10^6 kcal/hr (640 x 10^6 Btu/hr) non consumptive use.

(5) Consumptive use.

TABLE 6.3

CHARACTERIZATION OF SOLID AND LIQUID WASTES

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHED TAILS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	COMBUS-TION ASH	OFFGAS SCRUBBER SOLIDS
Solid Flows	mtpd	2.3	0.22	0.11	9,500	1,700	8.5	90	34
	tpd	2.5	0.24	0.12	10,600	1,900	9.4	100	37
Liquid Flows	m^3/hr				394	65	0.4		5.7
	gpm				1730	290	1.8		25
Temperature	°C/°F	25/77	40/104	25/77	30/86	50/122	25/77	90/194	45/113
Constituents:		. Lead . Lead Sulfate . Manganese Dioxide	. Unk	. Carbon	. Manganese Dioxide . Manganese Monoxide . Manganese Carbonate . Iron Oxide . Copper . Nickel Oxide . Zinc . Copper Oxide . Zinc Oxide . Sea Salt . Aluminum Oxide . Sodium Oxide . Magnesium . Ammonium . Sulfuric Acid . Sodium Cobalt	. Silica . Aluminum Oxide . Calcium Sulfate . Nickel . Cobalt	. Limestone . Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc	. Calcium Sulfate . Calcium Sulfite . Silica . Aluminum Oxide . Manganese Dioxide . Etc
Chemical Characteristics:		A			A, D	A, D	B, E	A	A, B
Physical Characterisitcs:		D			A, B	B	B		B

KEY:	CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 6.4

COMPOSITION OF GASEOUS EFFLUENT STREAMS

STREAM		DUST CONTROL EXHAUSTS	COPPER TANK HOUSE EXHAUST	NICKEL TANK HOUSE EXHAUST	LEACH REACTOR VENT	DRYER EXHAUST	AMMONIA SCRUBBER VENT	STACKED GASES	PROCESS VENTS	LEACH VENT	REDUCTION REACTOR VENT
Total Flow,	m^3/min	1,420	147	180	5.7	2.8	220	6,940	249	147	0.6
	scfm	50,000	5,200[(1)]	6,400[(1)]	200	100	7,800	245,000	8,800	5,200	20
Temp.	°C	25	50	50	160	90	25	155	40	40	40
	°F	77	122	122	320	194	77	311	104	104	104
Press., Atmosphere		1	1	1	1.1	1.1	1.1	1.1	1	1	1.1
% Oxygen		21	7	7.5	0.2	2	20	4	15	16	
Nitrogen		79			1.8	43	77	73	60	77	
Ammonia							TR	TR			
Carbon Monoxide								TR			
Carbon Dioxide						6		13	20		
Methane											
Hydrogen				0.5							10
Water			93	92	98	48	3	10	5	7	90
Hydrogen Sulfide, Sulfur Dioxide								TR			

---

(1) Cell exhaust only, excluding building ventilation.

TABLE 6.5

DISTRIBUTION OF POTENTIALLY TOXIC ELEMENTS

Element	Input Rate To Plant kg/day	(lbs/day)	Distribution As Percent Reporting To Waste	Product
Barium	34,500	76,000	100	0
Lanthanum	14,100	31,000	50	50
Vanadium	3,450	7,600	11	89
Chromium	86	190	90	10
Silver	27	60	10	90
Cadmium	172	380	5	95
Arsenic	436	960	11	89
Antimony	263	580	11	89
Thallium	1,730	3,800	51	49
Lead	4,360	9,600	90	10

be required in the process areas, but the main stack height could be significant, depending on local meteorological conditions.

The materials movement in and out of the plant are significant: excluding raw nodules and waste products, in excess of 5000 mtpd (5500 tpd) of fuels and process materials are brought in and 218 mtpd (240 tpd) of products are shipped out. Thus, the transportation network supporting plant operations must include highway and rail connections capable of supporting considerable traffic. The coal, lime and limestone, ammonia and hydrogen sulfide, and sulfuric acid would be delivered and copper and nickel would be shipped by rail. Most other materials and supplies would be trucked.

Manufacturing operations within the plant will be on a three shift, 365 day per year basis. It is estimated that about 500 people will be employed in the facility, including operating and maintenance labor, supervision, and plant general and administrative personnel. The mix of skill levels would be typical of a chemical processing plant, with about one third being skilled tradesmen and lead operators, one third unskilled laborers, and one third professional/management and clerical/support personnel.

The plant resource requirements including energy and water requirements already stated in Section 6.3 are summarized in Table 6.6.

TABLE 6.6

PLANT RESOURCE REQUIREMENTS

Item	Quantity
Land	73 hectares, 180 acres
Manpower	500 Persons
Water	12.5 m^3/min, 3300 gpm
Energy	
Coal	1000 mtpd, 1100 tpd
Electricity	28.8 MW

6.5 WASTE TREATMENT

The types of waste treatment which could rationally be carried out on the wastes from a process plant were described in Section 3.12. In this section the impact of treatment in terms of changes in the material and energy balances for the high temperature sulfuric acid process are identified. These are presented on Table 6.7.

6.6 ACCIDENTAL RELEASE POTENTIAL

The inventory of potentially hazardous liquids and gases which would be stored at the plant site or are "in-process" for the high temperature sulfuric acid process are summarized in Table 6.8.

TABLE 6.8

INVENTORY OF POTENTIALLY HAZARDOUS SUBSTANCES

Total Liquid	91,000 tonnes	(100,000 Tons)
+ Solids	27,000 tonnes	(30,000 Tons)
Sulfuric Acid, Dilute	86,000 tonnes	(94,000 Tons)
Ammonia	180-360 tonnes	(200-400 Tons)
Chlorine	23 tonnes	(25 Tons)
Hydrogen Sulfide	360-550 tonnes	(400-600 Tons)
Fuels	450-730 tonnes	(500-800 Tons)

The hazards summary for accidental release of the items inventoried for this process are summarized in Table 6.9.

TABLE 6.7

WASTE TREATMENT IMPACT ON PLANT REQUIREMENTS

	Base Case		Treatment Method					
Materials/Services Required	pH Adjustment Only		Precipitate Toxic Elements Only		Precipitate Toxic Elements and Wash Solids		Precipitate Toxic Elements, Wash, and Dry Solids	
			ADDITIONAL MATERIALS/SERVICES REQUIRED					
Coal, mtpy x 10^3 (tpy x 10^3)	330	(363)			124	(136.3)	517	(568.5)
Lime, mtpy x 10^3 (tpy x 10^3)	346	(380)	257	(282)	257	(282)	257	(282)
Limestone, mtpy x 10^3 (tpy x 10^3)	148	(163)			4.2	(4.6)	17.5	(19.2)
Sorbent, mtpy x 10^3 (tpy x 10^3)		0			1.8	(2)	1.8	(2)
HCl (37%), mtpy (tpy)		0			820	(900)	820	(900)
Flocculants, mtpy x 10^3 (tpy x 10^3)		1			1.4	(1.5)	1.4	(1.5)
Water, M^3/yr x 10^6 (gpy x 10^6)	5.8	(1540)			1.1	(291)	1.3	(351)
Power, kWh x 10^6	48.9		1.2		70.5		32.5	
Wastes Produced			ADDITIONAL WASTES PRODUCED					
Stacked gases, m^3/min x 10^3 (scfm x 10^3)	6.9	(245)			1.8	(62.8)	18.7	(659.7)
Cooling tower evaporation, m^3/min x 10^3 (scfm x 10^3)	5.9	(213)			2.6	(93.4)	2.8	(99.8)
Solid wastes, mtpy x 10^3 (tpy x 10^3)	3840	(4220)	670	(736.5)	686	(754.0)	736	(808.4)
Liquid wastes, m^3/yr x 10^6 (gpy x 10^6)	4.2	(1120)			0.08	(19.9)	0.23	(60.8)

TABLE 6.9

HAZARDS SUMMARY

Acid Mist Release	- 10^{-4} Per Year
Large Liquid Releases	- 10^{-7} Per Year
Large Gas Releases	- 10^{-7} Per Year
Ammonia	- 500 mg/l (or ppm) (level of concern) to 13 km (8 Miles)
Hydrogen Sulfide	- 50 mg/l (or ppm) (level of concern) to 18 km (11 Miles)
Chlorine	- 50 mg/l (or ppm) (level of concern) to 9 km (5.6 Miles)

The sulfuric acid leach vessels, which would be operated at 42 kg/cm^2 (600 psi) could rupture and produce a large cloud of acid mist, 450 to 540 metric tons (500 to 600 tons) at 10 percent concentration. Beyond that point, however, the system accident exposures would be similar to those for the reduction/ammonia leach process. Specific exceptions are the storage of much greater volumes of liquid sulfuric acid onsite, and the lack of a gasification unit. A pregnant liquor tank of 5680 cubic meters (1.5 million gallons) is the largest single component. Other large tanks in the process would be slightly smaller than their ammoniacal process counterparts.

6.7 NOISE ASSESSMENT

The basis upon which this noise assessment was developed is discussed in Section 3.13. The noise level at the plant boundary is estimated at between 48 and 58 dBA. This noise level is shown graphically on Figure 6.3. This level corresponds with the noise that would be present in a large store accounting office.

TYPICAL A-WEIGHTED SOUND LEVELS

At a Given Distance From Noise Source	Decibels RE: 20 N/m^2	Environmental
	140	
50 HP SIREN (100 FT)		
	130	
JET TAKEOFF (200 FT)		
	120	
RIVETING MACHINE	110	CASTING SHAKEOUT AREA
CUTOFF SAW		
PNEUMATIC PEEN HAMMER	100	ELECTRIC FURNACE AREA
TEXTILE WEAVING PLANT		
SUBWAY TRAIN (20 FT)	90	BOILER ROOM
		PRINTING PRESS PLANT
PNEUMATIC DRILL (50FT)		
	80	TABULATING ROOM
		INSIDE SPORT CAR (50 MPH)
FREIGHT TRAIN (100 FT)		
VACUUM CLEANER (10 FT)	70	
SPEECH (1 FT)		
		NEAR FREEWAY (AUTO TRAFFIC)
	60	LARGE STORE
		ACCOUNTING OFFICE
LARGE TRANSFORMER (200 FT)		PRIVATE BUSINESS OFFICE
HIGH TEMPERATURE SULFURIC ACID PROCESS	50	LIGHT TRAFFIC (100 FT)
		AVERAGE RESIDENCE
	40	MIN LEVELS RESIDENTIAL AREAS IN CHICAGO AT NIGHT
SOFT WHISPER (5 FT)		
	30	STUDIO (SPEECH)
	20	STUDIO FOR SOUND PICTURES
	10	
THRESHOLD OF HEARING YOUTHS 1000-4000 Hz	0	

FIGURE 6.3 ESTIMATED NOISE LEVEL AT PLANT BOUNDARY

7.0 REDUCTION/HYDROCHLORIC ACID LEACH PROCESS

7.1 INTRODUCTION

Copper, nickel, cobalt and manganese would be recovered from nodules by this process. In contrast to the three-metal processes where there are existing commercial projects using similar technology, no plants are operating using the hydrochloric acid technology. Therefore, the only data comes from patent literature and the details of the chemistry of this process are uncertain in many areas. Nevertheless, since this process has been patented by one of the major consortia and appears to be technically feasible, it has been included in this study.

A simplified block diagram of the reduction/hydrochloric acid leach process is shown on Figure 7.1. In this process the incoming nodules are ground and dried. Then the manganese, copper, nickel, and cobalt are liberated from dried nodules by a high temperature (500°C, 932°F) gaseous hydrogen chloride roasting of nodules. Hydrogen chloride reduces manganese dioxide to manganous chloride (liberating chlorine gas) and also reacts with other metal oxides to form soluble chloride salts. A hydrolysis reaction and quench follow, where water is sprayed on the nodules and the iron is convested to ferric oxide. The nodules are leached with aqueous hydrogen chloride, forming a concentrated pregnant liquor of chloride salts. Copper is extracted by liquid ion exchange reagents from the pregnant liquor, stripped and recovered as electrowon cathodes. Cobalt is solvent-extracted from the copper raffinate, stripped, and separated by precipitation with hydrogen sulfide and is recovered from the sulfide precipitate by selective leaching and hydrogen reduction, along with some nickel, zinc and copper. Nickel is extracted by liquid ion exchange reagents from the cobalt raffinate, stripped and recovered as electrolytic cathodes. The nickel raffinate is evaporated, crystallizing manganese chloride as well as the other remaining chloride salts. The salts are dried using combustion gases in a counter-current dryer. The dried salts are charged to a high temperature fused salts electrolysis furnace, where molten manganese metal is tapped and cast as product and chlorine gas is liberated. Excess hydrogen chloride gas in the process is recovered and recycled. Generated chlorine gas is recovered, dried and delivered to a local chemical complex which, in exchange, returns make-up hydrogen chloride to the process.

In subsequent paragraphs of this chapter a more detailed process flow diagram is presented and discussed along with a summary of the plant inputs and outputs; the plant support requirements; waste treatment alternatives and their impacts on material and energy balances; accidental release of hazardous substances potential; and noise generated by the plant. A detailed description of this process is presented in Volume III.

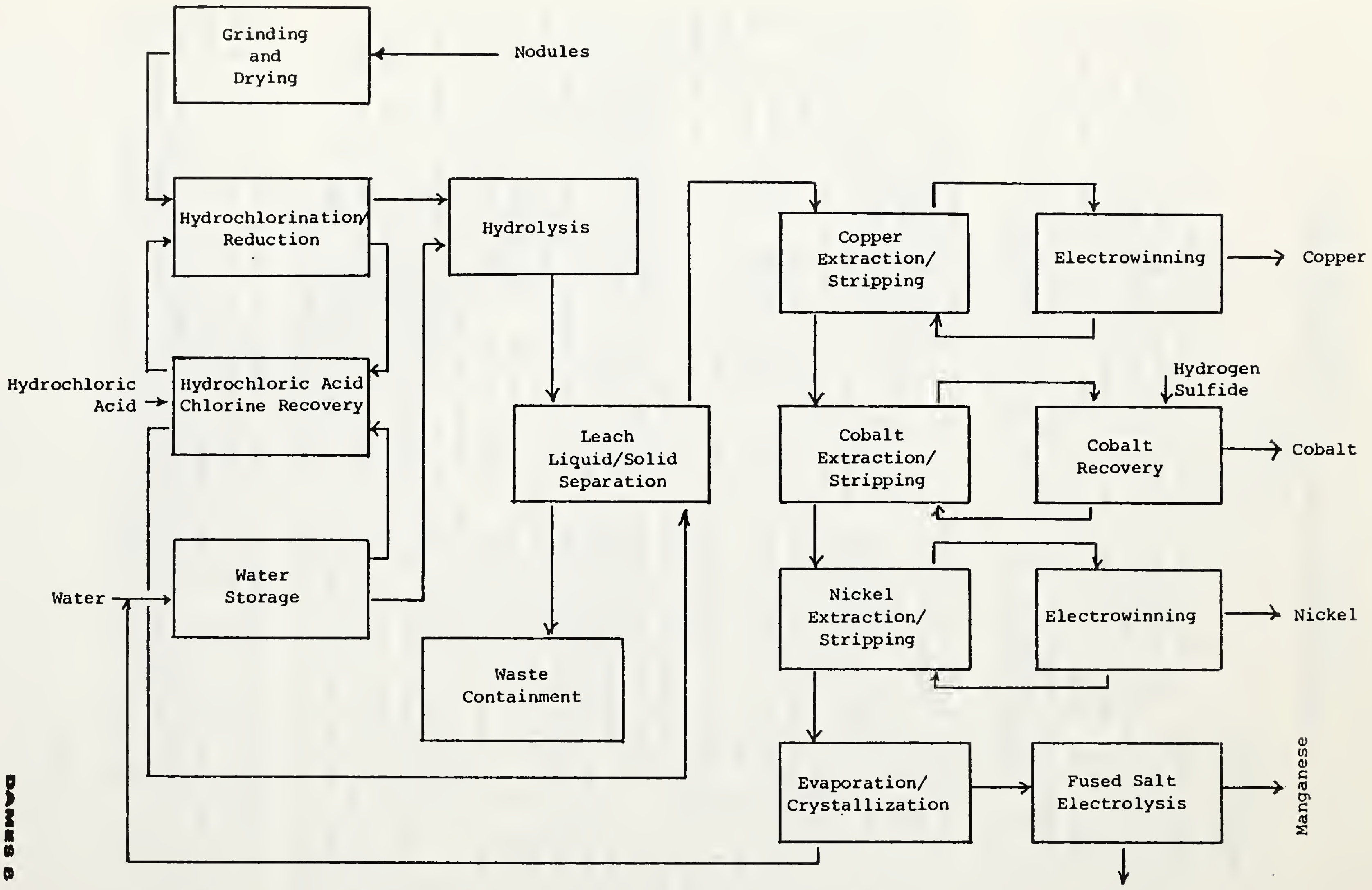
Grinding and Drying
Nodules
Hydrochlorination/ Reduction
Hydrolysis
Hydrochloric Acid
Hydrochloric Acid Chlorine Recovery
Water
Water Storage
Leach Liquid/Solid Separation
Waste Containment
Copper Extraction/ Stripping
Electrowinning
Copper
Cobalt Extraction/ Stripping
Hydrogen Sulfide
Cobalt Recovery
Cobalt
Nickel Extraction/ Stripping
Electrowinning
Nickel
Evaporation/ Crystallization
Fused Salt Electrolysis
Manganese

FIGURE 7.1 REDUCTION/HYDROCHLORIC ACID LEACH PROCESS

7.2 PROCESS DESCRIPTION

The reduction/hydrochloric acid leach process is summarized in Figure 7.2. The first step in the process is to grind and dry the nodules. The next step is the chemical reduction of the insoluble manganese dioxide matrix of the nodules with hydrogen chloride to yield soluble manganous chloride, thereby releasing the nickel, copper and cobalt to the solution with simultaneous oxidation of a portion of the hydrochloric acid to chlorine. Unreacted hydrogen chloride is separated from the accompanying chlorine and water vapor and recycled. Separation is accomplished by absorption of hydrogen chloride in concentrated hydrochloric acid, in which chlorine has very limited solubility. The remaining chlorine gas is dried by passage through concentrated sulfuric acid.

Extensive solubilization of the iron content of the nodules is prevented by following initial high temperature (500°C, 932°F) reaction of the nodules with gaseous hydrogen chloride, with a water spray. This results in the conversion (hydrolysis) of the iron chloride produced in the initial step to insoluble iron (ferric) oxide, simplifying subsequent metals separation and reducing hydrogen chloride regeneration requirements. In the next step, the soluble metal chlorides, including particularly those of manganese, nickel, copper and cobalt, are brought into solution with hydrochloric acid to form a concentrated pregnant leach solution. In the hydrochloric acid leach process, as distinct from the other nodules treatment processes, the major metals separation steps are carried out from chloride solution.

In the base-case process, copper is selectively extracted from the pregnant leach liquor by contact with an organic liquid ion exchange medium. In the extraction, copper ions displace hydrogen ions in the liquid ion exchanger. After separation of the copper-loaded organic phase from the copper-depleted aqueous chloride solution, the copper is back-extracted into a strong sulfuric acid solution. In this step, called stripping, the extraction is reversed, and the resulting copper sulfate solution is sent to electrowinning. Copper electrowinning produces cathode copper for sale and a partially copper-depleted, strong sulfulric acid "spent" electrolyte which is returned to the liquid ion exchange circuit to strip more copper.

The chloride leach solution (raffinate) from which the copper has been removed is neutralized and passed to a solvent extraction step, where an organic liquid reagent selectively removes the cobalt (as its complex chloroanion) from the nickel and manganese. The cobalt is recovered in a sequence of steps that includes stripping from the organic solvent with recycled process water, precipitation as cobalt sulfide by hydrogen sulfide, selective leaching and, finally, hydrogen reduction to cobalt powder.

The copper and cobalt-depleted solution is next sent to a liquid ion exchange circuit where nickel is selectively separated from the

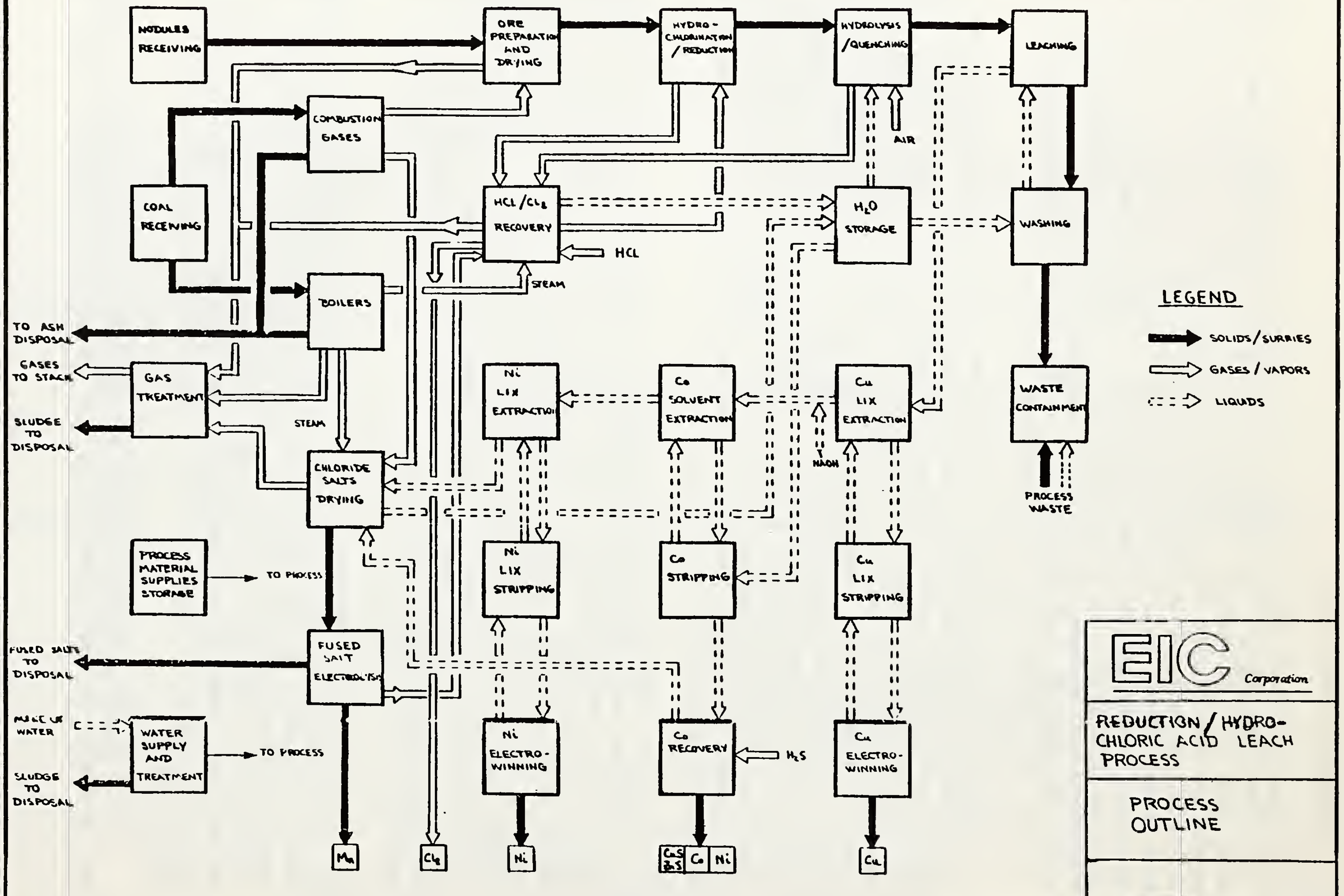
NODULES RECEIVING
ORE PREPARATION AND DRYING
HYDRO-CHLORINATION / REDUCTION
HYDROLYSIS / QUENCHING
LEACHING
COMBUSTION GASES
COAL RECEIVING
HCL / CL_2 RECOVERY
HCL
STEAM
H_2O STORAGE
AIR
WASHING
BOILERS
TO ASH DISPOSAL
GASES TO STACK
GAS TREATMENT
SLUDGE TO DISPOSAL
STEAM
CHLORIDE SALTS DRYING
Ni LIX EXTRACTION
Co SOLVENT EXTRACTION
Cu LIX EXTRACTION
NaOH
WASTE CONTAINMENT
PROCESS WASTE
LEGEND
SOLIDS / SURRIES
GASES / VAPORS
LIQUIDS
PROCESS MATERIAL SUPPLIES STORAGE
TO PROCESS
Ni LIX STRIPPING
Co STRIPPING
Cu LIX STRIPPING
FUSED SALT ELECTROLYSIS
FUSED SALT TO DISPOSAL
MAKE UP WATER
WATER SUPPLY AND TREATMENT
TO PROCESS
SLUDGE TO DISPOSAL
Ni ELECTRO-WINNING
Co RECOVERY
H_2S
Cu ELECTRO-WINNING
Mn
Cl_2
Ni
CuS ZnS
Co
Ni
Cu
EIC Corporation
REDUCTION / HYDRO-CHLORIC ACID LEACH PROCESS
PROCESS OUTLINE
NC-0015-CL
REV. 0

FIGURE 7.2

manganese and stripped into a sodium sulfate solution for nickel electrowinning. Nickel separation has many features in common with copper separation, except that much lower acid concentrations are appropriate in the case of nickel, which also is produced as cathodes for sale.

Of the several options for manganese recovery from nodules, that selected for the base-case process involves evaporation of the final aqueous chloride solution to produce a dry, impure manganese chloride. The manganese chloride is charged to a high temperature electrolysis furnace, where it dissolves in a molten alkali chloride bath. Electrolysis of the bath liberates molten manganese, which is tapped from the furnace, cast into molds and sold as manganese metal. Fused salt impurities are also skimmed off, solidified and sent to waste disposal.

The second major product of the electrolysis is chlorine gas, which would be recovered along with the chlorine produced in the initial hydrochlorination step. Recovered chlorine would need to be reconverted to hydrogen chloride or otherwise utilized off-site in a large scale chemical process, such as the manufacture of polyvinyl chloride.

Plant services include facilities for raising the necessary steam and part of the power required for process use, supplying the make-up water and cooling required, and providing for materials handling for process materials and supplies.

While data on the reduction of nodules with hydrogen chloride and subsequent recovery of metal values from acid chloride solution have been reported in the patent literature, this technology currently has no direct analog in commercial extractive metallurgy. Also, while the thermodynamics of the reduction step are well known, and reports on laboratory studies of some separations of metals from chloride solutions are available, no data exist to indicate the expected properties of the nodule residues (e.g., filtering rates) or the problems associated with recovering a salable manganese metal from impure chloride solutions. Thus, the proposed process configuration has been established based on literature data which contain little detailed engineering and design information and without the benefit of insights which might be gained from analogies to conventional technology in related operations. This means that alternative process configurations might well be technically and economically more attractive, but access to more data would be required to make such a judgement.

One alternative configuration would involve the reduction of nodules by strong aqueous hydrochloric acid, thus eliminating the costs of drying nodules for high temperature roasting. However, iron would then be dissolved, and its removal would require additional and probably costly process steps. Alternating processes for the separation and purification of copper, nickel and cobalt are possible but would have little impact on overall process inputs and outputs.

Alternative methods for manganese recovery would, however, have major impacts since it is the major metal produced. Direct electrodeposition from impure chloride solution, if possible, would simplify the process scheme. Precipitation on aluminum, i.e. cementation, has also been suggested and, while probably reducing energy requirements, it would require additional process steps and involvement with the scrap aluminum/alumina markets.

A key process alternative, and one which will impact siting requirements considerably, pertains to the arrangement for returning hydrogen chloride to the process by exchange for or regeneration from the chlorine evolved. While a buy-back arrangement with an adjacent hydrochlorination facility has been assumed, hydrogen chloride could be regenerated on site by burning evolved and purchased make-up chlorine with purchased hydrogen, or hydrogen formed from purchased hydrocarbons or coal. Obviously, each alternative would have a distinctly different set of inputs and outputs, but the operation would be on a large scale for any of the options mentioned.

7.3 PLANT INPUTS AND OUTPUTS

The major items which comprise the material and energy balances for the reduction/hydrochloric acid leach process are summarized in Table 7.1. Included are production rates for the saleable products, consumption rates for major materials and supplies, raw materials requirements and a breakdown of the amounts of solid liquid and gaseous wastes and the requirements for fuels and purchased power.

The distribution of services required within the plant is summarized on Table 7.2. The services include process power, process steam, cooling water and process water.

The composition of the output streams which constitute process wastes is summarized on Tables 7.3 and 7.4 for the solid and liquid and gaseous wastes, respectively. These compositions were derived from the overall plant material balance and are presented for only the major materials in the process. Where trace amounts of a material are indicated, it has been assumed that previous removal steps will have reduced it to a level which is either acceptable for discharge directly or it is present in amounts too low to quantify within the accuracy of the methods used in this study.

In contrast to the previously described three-metal processes where essentially all of the process wastes are produced in slurry form, approximately one-half of the solid wastes from the hydrochloric acid process will be produced as fused salts. These salts are soluble, would require containment in a sealed area such as a tailings dam, and could not be transported as a slurry.

TABLE 7.1

MAJOR PLANT INPUTS AND OUTPUTS

MAJOR INPUTS

Nodules	1.4×10^6 mtpy	1.25×10^6 tpy
Coal	0.42×10^6 mtpy	0.46×10^6 tpy
Water	4.13×10^6 m^3/yr	1.09×10^9 gpy
Hydrogen Chloride	0.66×10^6 mtpy	0.73×10^6 tpy
Gases	2.1×10^3 mtpy	2.3×10^3 tpy
Liquids	3.8×10^3 m^3/yr	1000×10^3 gpy
Solids	1.4×10^3 mtpy	1.5×10^3 tpy
Purchased Power	94.5 MW	

MAJOR OUTPUTS

Solid Wastes	504×10^3 mtpy	554×10^3 tpy
Liquid Wastes	0.83×10^6 m^3/yr	220×10^6 gpy
Stacked Offgases	16×10^3 m^3/min	565×10^3 scfm
Low Level Emissions	1.6×10^3 m^3/min	56×10^3 scfm
Cooling Tower Evaporation	7.5×10^3 m^3/min	266×10^3 scfm
Copper	8.6×10^3 mtpy	9.57×10^3 tpy
Nickel	10.8×10^3 mtpy	11.9×10^3 tpy
Cobalt	1.8×10^3 mtpy	2.0×10^3 tpy
Manganese	188×10^3 mtpy	207×10^3 tpy

A summary of the flows and distribution of potentially toxic elements for the reduction/hydrochloric acid leach process is presented in Table 7.5. As in the three-metal processes, the toxic elements are mostly either in the product and of no concern or are in the wastes in a chemically stable form similar to their form in the raw nodules. The relatively small proportion of the toxic elements which are altered chemically in processing would mostly be solubilized and then reprecipitated as inert compounds prior to disposal. The tailings could be satisfactorily stored in a lined tailings containment facility.

7.4 PLANT RESOURCE REQUIREMENTS

It is estimated that the total plant facility including processing and support facilities but excluding long term waste containment areas, will require approximately 40 hectares (100 acres) of land. Within the hydrometallurgical processing area, the plant layout will involve equipment densities which are typical for the chemical processing industry. Separate processing buildings would be provided for the liquid ion exchange operation and for copper and nickel electrowinning, manganese electrolysis and cobalt recovery. Nodule drying and hydrochlorination

TABLE 7.2

SERVICES PROFILE

	Process Power	Process Steam		Cooling Water		Process Water	
	kW	kg/hr x 10^3	pph x 10^3	m^3/min	gpm	m^3/min	GPM
Ore Preparation and Drying	1,100	-	-	-	-	-	-
Hydrochlorination	1,700	7.7	16.9	25.8	6,800	0.04	11.8
Leaching/Washing	300	-	-	26.1	6,900	0.01	2.1
Liquid Ion Exchanges	400	1.7	3.7	1.4	360	0.11	29
Copper Electrowinning	3,300	1.2	2.6	-	-	0.03	7.6
Nickel Electrowinning	5,600	1.5	3.3	-	-	0.03	7.5
Manganese Recovery	100,750	48.9	107.6	19.7	5,200	0.01	3.6
Cobalt Recovery	350	3.9	8.6	3.8	1,000	-	-
Hydrogen Chloride Recovery	1,800	300	660	273	72,200	-	-
Waste Recovery	100	2.5	5.5	0.8	210	0.45	120
Materials Handling	650	-	-	-	-	-	-
Services	7,950	-	-	5.7	1,500	8.03	2,120
	(29,500)(1)	86(2)	190(2)				
TOTAL	94,500	368	810	356(3)	94,200(3)	8.7(4)	2,300(4)

(1) Generated internally.

(2) Used internally in power generation.

(3) 212 x 10^6 kcal/hr (850 x 10^6 Btu/hr), non consumptive use.

(4) Consumptive use.

TABLE 7.3

CHARACTERIZATION OF SOLID AND LIQUID WASTES

STREAM		LEACHED TAILS	FUSED SALTS	COPPER TANK HOUSE PURGE	NICKEL TANK HOUSE PURGE	COPPER LIX CRUD	NICKEL LIX CRUD	GAS TREATMENT SOLIDS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	COMBUS-TION ASH	SOLIDS FROM SULFURIC ACID PURGE
Solid Flows	mtpd	720	640	0.16	0.55	0.04	0.04	43	25	5.4	114	0.22
	tpd	800	700	0.18	0.60	0.04	0.04	48	28	6.0	125	0.24
Liquid Flows	m^3/hr	90						7	6	0.7		
	gpm	400						31	27	3		
Temperature	°C/°F	40/104	25/77	25/77	25/77	40/104	40/104	45/113	110/230	25/77	90/194	40/104
Constituents:		. Clays . Ferrous Hydroxide . Aluminum Hydroxide	. Salts	. Lead . Lead Sulfate . Manganese Dioxide	. (?)	. UNK	. UNK	. Magnesium	. Gypsum . Silica . Aluminum Oxide . Etc	. Limestone . Silica . Aluminum Oxide . Etc	. Silica . Aluminum Oxide . Etc	. Nodule Dust
Chemcial Characteristics:		A, D	C	A	A			A,B,D,E	A,B, D, E	B, E	A, B	
Physical Characteristics:		A, B	E	D	D			B	B	B		D

KEY:

	CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 7.4

COMPOSITION OF GASEOUS EFFLUENT STREAMS

Stream		Nodules Dryer Off Gas	Copper Tank House Exhaust	Nickel Tank House Exhaust	Chloride Salts Dryer Off Gas	Fugitives from Electrolysis	CO Leach Vent	HCl Recovery Vent	Dust Control Coal/ Limestone	Stack Gas	Ammonia Scurbber Unit
Total flow	m^3/min	1,510	44.4*	53.5*	1,840	4,250	65.1	1,200	1,415	15,000	3.4
	scfm	53,500	1,570	1,890	66,200	150,000	2,300	42,400	50,000	530,000	120
Temperature	°C	175	50	50	125	50	40	40	25	125	40
	°F	347	122	122	257	122	104	104	77	257	104
Pressure, atmospheres		1.05	1	1	1.05	1.05	1	1.1	1.05	1	1.05
% O_2		10	7	7.5	1.7	20.9	16	19.8	21		20
% N_2		58			32.3	78.9	77	74.4	79		77
% HCl					0.2						
% Cl_2						0.2					
% CO_2		5			5.9						
% H_2O		27	93	92	60		7	5.8			3
% H_2S, SO_2		0.03									
% H_2				0.5							
% NH_3											TR

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* Cell exhaust only, excluding building ventilation

TABLE 7.5

DISTRIBUTION OF POTENTIALLY TOXIC ELEMENTS

Element	Input Rate To Plant kg/day	Input Rate To Plant (lbs/day)	Distribution As Percent Reporting To Waste	Distribution As Percent Reporting To Product
Barium	10,000	22,000	100	0
Lanthanum	4,000	8,800	100	0
Vanadium	1,000	2,200	14	86
Chromium	30	66	90	10
Silver	8.2	18	90	10
Cadmium	50	110	1	99
Arsenic	132	290	11	89
Antimony	77	170	11	89
Thallium	500	1,100	51	49
Lead	1,320	2,900	90	10

and hydrogen chloride and ammonia recovery would be outside installations. A boiler house/power house and banks of cooling towers would be located adjacent to the chemical process areas, and offices, laboratories, maintenance shops, warehouses, control houses, and a change house/cafeteria and parking area would also be located close to the main processing area. While the aforementioned facilities would require about 8 to 16 hectares (20-40 acres) of land, an equal amount is needed to provide materials storage areas. The nodules storage and decant ponds, a chlorine/hydrogen chloride storage area, coal and lime and limestone storage areas, and a plant run off and emergency waste storage area would require at least 16 hectares (40 acres), including margins, of relatively flat terrain. No unusually tall structures would be required in the process areas, but the main stack height could be significant, depending on local meteorological conditions.

The materials movement in and out of that plant are significant: excluding raw nodules, chlorine and hydrogen chloride, and waste products, in excess of 1350 mtpd (1500 tpd) of fuels and process materials are brought in and 630 mtpd (700 tpd) of products are sold. Chlorine and hydrogen chloride movements are 1530 and 2000 mtpd (1700 and 2200 tpd) respectively. Thus, the transportation network supporting plant operations must include highway and rail connections capable of supporting considerable traffic. The coal, lime and limestone, caustic and hydrogen sulfide, and sulfuric acid would be delivered and copper, nickel and manganese would be shipped by rail. Most other materials and supplies would be trucked, except that chlorine and hydrogen chloride would be exchanged over-the-fence.

Manufacturing operations within the plant will be on a three shift, 365 day per year basis. It is estimated that about 300 people will be employed in the facility, including operating and maintenance labor, supervision, and plant general and administrative personnel. The mix of skill levels would be typical of a chemical processing plant, with about one third being skilled tradesmen and lead operators, one third unskilled laborers, and one third professional/management and clerical/support personnel.

The plant resource requirements including energy and water requirements already stated in Section 7.3 are summarized in Table 7.6.

TABLE 7.6

PLANT RESOURCE REQUIREMENTS

Item	Quantity
Land	40 hectares, 100 Acres
Manpower	300 Persons
Water	8.7 m^3/min, 2300 gpm
Energy	
Coal	1180 mtpd, 1300 tpd
Electricity	94.5 MW

7.5 WASTE TREATMENT

The types of waste treatment which could rationally be carried out on the wastes from a process plant were described in Section 3.12. In this section the impact of treatment in terms of changes in the material and energy balances for the reduction/hydrochloric acid process are identified. These are presented in Table 7.7.

7.6 ACCIDENTAL RELEASE POTENTIAL

The inventory of potentially hazardous liquids and gases which would be stored at the plant site or are "in-process" for the reduction/hydrochloric acid leach process are summarized in Table 7.8.

TABLE 7.8

INVENTORY OF POTENTIALLY HAZARDOUS SUBSTANCES

Total Liquid	23,600 tonnes	(26,000 tons)
+ Solids	8,200 tonnes	(9,000 tons)
Sulfuric Acid, Dilute	450 tonnes	(500 tons)
Chlorine	90 tonnes	(100 tons)
Hydrogen Sulfide	270 tonnes	(300 tons)
Hydrogen Chloride	59,000 tonnes	(65,000 tons)
Fuels	71,000 tonnes	(78,000 tons)

TABLE 7.7

WASTE TREATMENT IMPACT ON PLANT REQUIREMENTS

	Base Case		Treatment Method					
Materials/Services Required	pH Adjustment Only		Precipitate Toxic Elements Only		Precipitate Toxic Elements and Wash Solids		Precipitate Toxic Elements, Wash, and Dry Solids	
			ADDITIONAL MATERIALS/SERVICES REQUIRED					
Coal, mtpy x 10^3 (tpy x 10^3)	418	(459)			25.3	(27.8)	113	(124)
Lime, mtpy x 10^3 (tpy x 10^3)	3.8	(4.2)	8.4	(8.9)	7.3	(8.0)	8.0	(8.9)
Limestone, mtpy x 10^3 (tpy x 10^3)	14.1	(15.5)			0.8	(0.9)	3.8	(4.2)
Sorbent, mtpy x 10^3 (tpy x 10^3)		0			1.8	(2)	1.8	(2)
HCl (37), mtpy (tpy)		0			234	(257)	234	(257)
Flocculants, mtpy x 10^3 (tpy x 10^3)	72.8	(80)			0.27	(0.3)	0.27	(0.3)
Water, m^3/yr x 10^6 (gpy x 10^6)	4.2	(1100)			0.24	(63.7)	0.28	(73.2)
Power, kWh x 10^6	756		0.3		0.8			
Wastes Produced			ADDITIONAL WASTES PRODUCED					
Stacked gases, m^3/min x 10^3 (scfm x 10^3)	15.7	(565)			0.5	(17.5)	2.2	(77)
Cooling tower evaporation, m^3/min x 10^3 (scfm x 10^3)	7.5	(266)			0.52	(18.5)	0.57	(20)
Solid wastes, mtpy x 10^3 (tpy x 10^3)	304	(334)	11.7	(12.9)	15.0	(16.5)	26.1	(28.7)
Liquid wastes, m^3/yr x 10^6 (gpy x 10^6)								

The hazards summary for accidental release of the items inventoried for this process are summarized in Table 7.9.

TABLE 7.9

HAZARDS SUMMARY

Large Liquid Releases - 10^{-7} Per Year
Large Gas Releases - 10^{-7} Per Year
  Hydrogen Chloride - 50 mg/l (or ppm) (level of concern) to 19 km (12 Miles)
  Chlorine - 50 mg/l (or ppm) (level of concern) to 19 km (12 Miles)
  Hydrogen Sulfide - 50 mg/l (or ppm) (level of concern) to 18 km (11 Miles)

In general, the basic frequency expectations established for other plants would apply to this case also with one major exception. In the reduction/hydrochloric acid leach process there are unusually large volumes of hydrogen chlorine and chlorine. Both of these are potentially dangerous. However, the plant itself represents far less hazard than the transport of these gases to the plant.

7.7 NOISE ASSESSMENT

The basis upon which this noise assessment was developed is discussed in Section 3.13. The noise level at the plant boundary is estimated at between 54 and 64 dBA. This noise level is shown graphically on Figure 7.3. This level corresponds approximately with the noise that would be generated near a freeway from auto traffic.

TYPICAL A-WEIGHTED SOUND LEVELS

At a Given Distance From Noise Source	Decibels RE: 20 N/m^2	Environmental
	140	
50 HP SIREN (100 FT)		
	130	
JET TAKEOFF (200 FT)		
	120	
RIVETING MACHINE CUTOFF SAW	110	CASTING SHAKEOUT AREA
PNEUMATIC PEEN HAMMER	100	ELECTRIC FURNACE AREA
TEXTILE WEAVING PLANT SUBWAY TRAIN (20 FT)	90	BOILER ROOM PRINTING PRESS PLANT
PNEUMATIC DRILL (50FT)		
	80	TABULATING ROOM INSIDE SPORT CAR (50 MPH)
FREIGHT TRAIN (100 FT) VACUUM CLEANER (10 FT) SPEECH (1 FT)	70	
		NEAR FREEWAY (AUTO TRAFFIC)
REDUCTION/HYDROCHLORIC LEACH PROCESS	60	LARGE STORE ACCOUNTING OFFICE
LARGE TRANSFORMER (200 FT)		PRIVATE BUSINESS OFFICE
	50	LIGHT TRAFFIC (100 FT) AVERAGE RESIDENCE
	40	MIN LEVELS RESIDENTIAL AREAS IN CHICAGO AT NIGHT
SOFT WHISPER (5 FT)		
	30	STUDIO (SPEECH)
	20	STUDIO FOR SOUND PICTURES
	10	
THRESHOLD OF HEARING YOUTHS 1000-4000 Hz	0	

FIGURE 7.3 ESTIMATED NOISE LEVEL AT PLANT BOUNDARY

8.0 SMELTING PROCESS

8.1 INTRODUCTION

Copper, nickel, cobalt and a ferromanganese alloy, if desired, can be recovered from nodules by a smelting process. Electric furnace technology is well developed and copper, nickel and ferromanganese are all currently produced by smelting processes. Some extension of present technology would be required to treat manganese nodules, but most of the necessary technology for this process is available.

A simplified block diagram of the smelting process is shown on Figure 8.1. The nodules smelting process is a combination pyrometallurgical and hydrometallurgical treatment of nodules to recover the value metals nickel, copper and cobalt, with the option of recovering ferromanganese or a storable by-product of manganese and iron. The smelting process produces a slag from which ferromanganese is recovered and a value-metal alloy matte composed primarily of nickel, copper, cobalt, and sulfur. The matte is granulated and slurried and selectively leached with sulfuric acid at elevated temperature and pressure. The leach residue and metalliferous solution are separated by a series of filtering and washing stages. After liquid/solid separation, copper and nickel are selectively extracted by liquid ion exchange, stripped from the ion exchange liquid into a weak electrolyte, and recovered as electrowon cathodes. Cobalt is separated from the raffinate by precipitation with hydrogen sulfide and is recovered from the sulfide precipitate by selective leaching and hydrogen reduction along with some nickel, copper and zinc. The essentially metal-free raffinate liquor is used to granulate waste slag. Ammonia required in the process is recovered by lime boil and recycled to the process for use in pH control.

In the subsequent paragraphs of this chapter a more detailed process flow diagram is presented and discussed along with a summary of the plant inputs and outputs, plant support requirements, waste treatment alternatives and their impacts on material and energy balances, accidental release of hazardous substances potential and noise generated by the plant. A detailed description of this process is presented in Volume III.

8.2 PROCESS DESCRIPTION

The smelting process is summarized in Figure 8.2. The nodules are first dried by direct contact with combustion gases to remove water not chemically bound to the minerals. The manganese dioxide and ferric oxide are then reduced to manganese and ferrous oxides by contact, in the presence of coke, with a carbon monoxide-rich producer gas at high temperature (725°C, 1337°F). The hot, reduced nodules are then charged to an electric furnace, along with coke and silica. In this step, most of the copper, nickel, cobalt and iron and some manganese are reduced (at

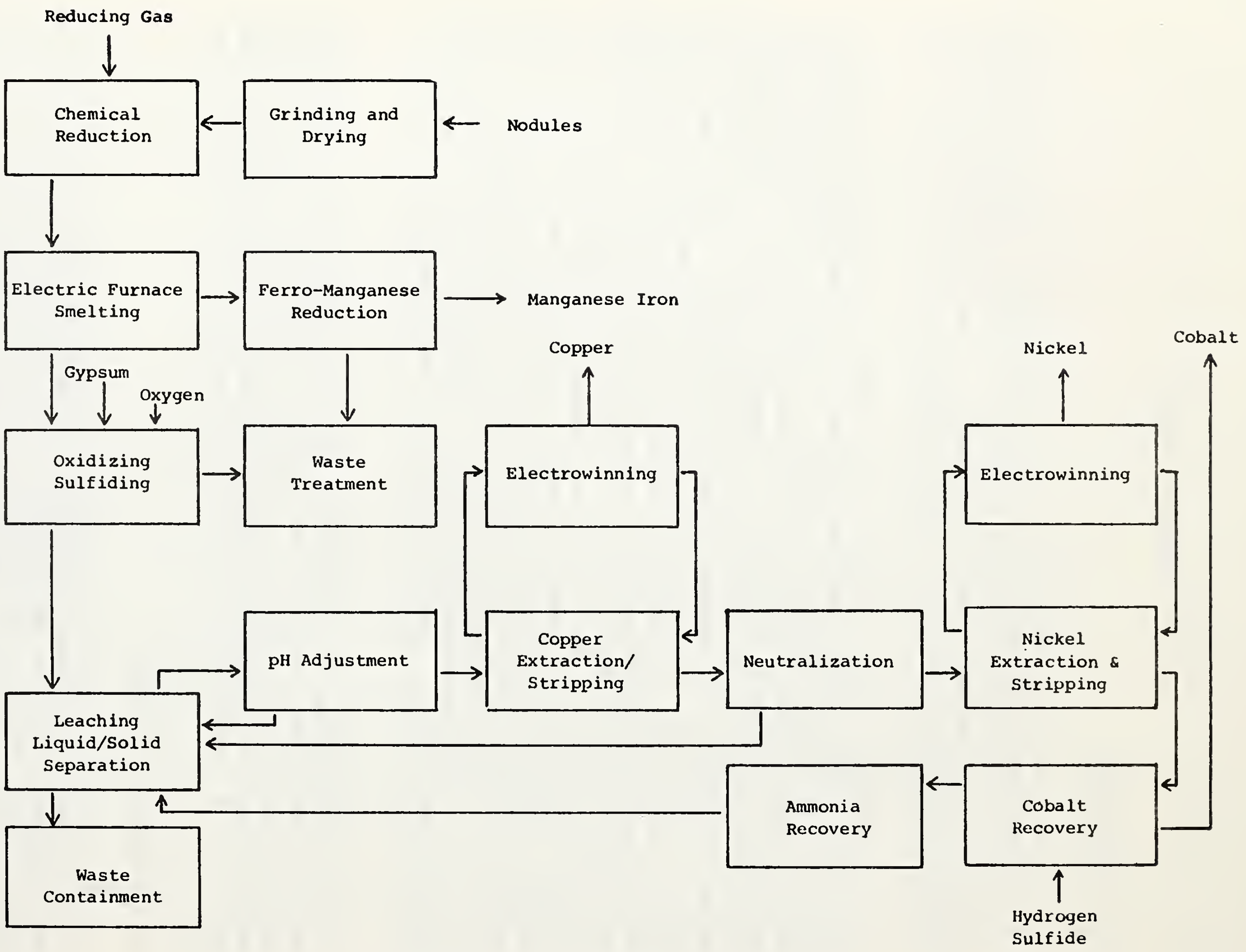


FIGURE 8.1 SMELTING PROCESS

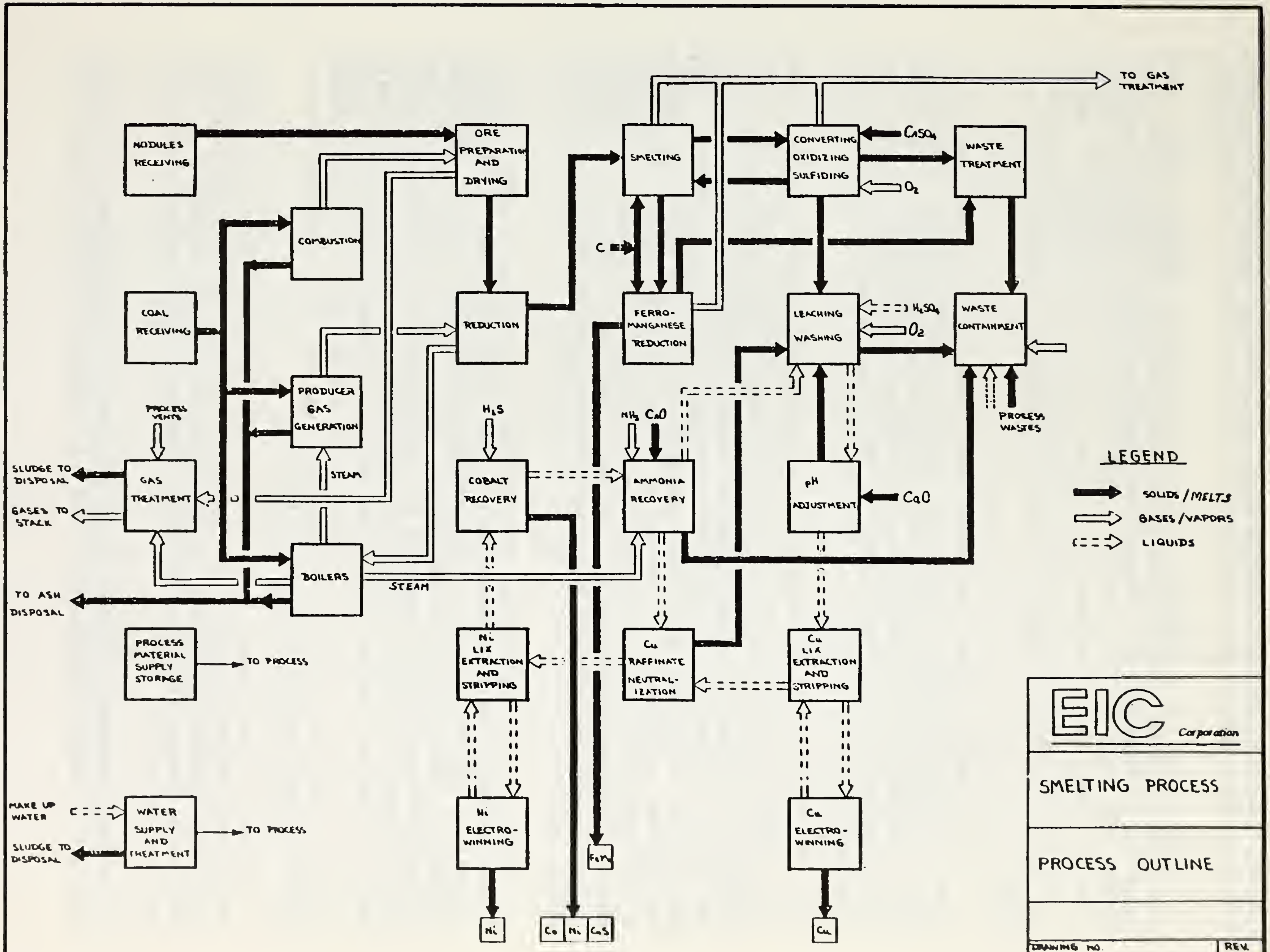

NODULES RECEIVING
COAL RECEIVING
ORE PREPARATION AND DRYING
COMBUSTION
PRODUCER GAS GENERATION
STEAM
REDUCTION
SMELTING
C
FERRO-MANGANESE REDUCTION
CONVERTING OXIDIZING SULFIDING
CaSO4
O2
WASTE TREATMENT
LEACHING WASHING
H2SO4
O2
WASTE CONTAINMENT
PROCESS WASTES
TO GAS TREATMENT
PROCESS VENTS
GAS TREATMENT
SLUDGE TO DISPOSAL
GASES TO STACK
BOILERS
STEAM
TO ASH DISPOSAL
H2S
COBALT RECOVERY
NH3 CaO
AMMONIA RECOVERY
pH ADJUSTMENT
CaO
LEGEND
SOLIDS/MELTS
GASES/VAPORS
LIQUIDS
PROCESS MATERIAL SUPPLY STORAGE
TO PROCESS
Ni LIX EXTRACTION AND STRIPPING
Cu RAFFINATE NEUTRAL-IZATION
Cu LIX EXTRACTION AND STRIPPING
MAKE UP WATER
WATER SUPPLY AND TREATMENT
SLUDGE TO DISPOSAL
TO PROCESS
Ni ELECTRO-WINNING
FeMn
Cu ELECTRO-WINNING
Ni
Co
Ni
CuS
Cu
EIC Corporation
SMELTING PROCESS
PROCESS OUTLINE
DRAWING NO.
NC-0019-SM
REV.
0

FIGURE 8.2

1425°C, 2597°F) and form a molten alloy phase, which separates by gravity from the unreduced manganese slag.

The alloy is transferred, hot, to converter vessels where, with additional silica, the manganese and most of the iron are re-oxidized with air, separated as a slag, and returned to the electric furnace. Gypsum and coke are then added to the alloy, producing a metal sulfide "matte" phase which contains the copper, nickel and cobalt. A second liquid/liquid separation is made in the converter, with the slag returned to the electric furnace and the matte granulated by quenching it in cold water.

The electric furnace manganese slag, with recycled iron-rich slags, may be further reduced (at 1480°C, 2696°F) with additional coke in an electric furnace to produce a molten ferromanganese alloy, if desired, which separates by gravity from the unreduced manganese slag. The ferromanganese is cast for sale, and the waste slag is granulated for disposal.

The metals are recovered from the granulated matte by dissolution into strong (5 percent), hot (110°C, 230°F) sulfuric acid solution in the presence of oxygen (at 10 atm pressure). The metal-bearing solution is subjected to a series of purification steps in which it is contacted with an organic medium which selectively removes the copper and nickel from the aqueous solution. Ammonia is added to the solution to control the pH during the separations. The metal values are, in turn, selectively removed from the organic fluid and transferred to acid aqueous solutions, which accumulate copper sulfate and nickel sulfate. The metal products, cathode copper and nickel, are produced from these solutions by electrodeposition.

Cobalt is then recovered from the aqueous ammonium sulfate solution by contacting it with hydrogen sulfide, which precipitates the insoluble sulfide of cobalt as well as small amounts of copper, nickel, and other metals not removed in previous steps. The solids are removed from the aqueous ammonium sulfate solution and contacted with air and hot (100°C, 212°F) sulfuric acid to selectively redissolve the cobalt and the small amount of nickel present. The undissolved sulfides are sold as minor products, and the cobalt and nickel are recovered from solution in powder form by selective reduction with hydrogen at high pressure (34 atm pressure) and temperature (185°C, 365°F).

Lime is then added to the metal free ammonium sulfate solution, and the mixture is contacted with steam (at 120°C, 248°F, 2 atm pressure) to recover ammonia for reuse in the process. The gypsum formed in this step is combined with other process solid and liquid wastes and sent to containment.

Plant services include facilities for generating the producer gas used in nodule reduction, raising the necessary steam and part of the power required for process use, supplying the make-up water and cooling required, and providing materials handling for process materials and supplies.

While detailed design information on the process implications involved in the smelting of nodules has not been published, enough is known about the thermodynamics of the system to permit a process outline to be constructed.

Electric furnace smelting is well developed technology, and copper and nickel are currently recovered by treatment of mattes formed during the smelting of sulfide ores. Ferromanganese of high purity is currently produced directly from high quality ores. Thus, the reductive smelting of nodules to ferromanganese with subsequent sulfidizing of the alloy phase to form a matte is a synthesis of technologies from different areas of extractive metallurgy. Detailed information on slag properties (particularly viscosity-composition-temperature relationships), the efficiencies of materials (coke, gypsum) and energy consumptions, and the distribution of minor metals and impurities among dust, slag, and matte phases under smelting conditions for this system, however, is lacking.

The oxidative dissolution of sulfide ores and mattes is well known, but the metal separation and purification schemes are specific to nodules and are complicated by the chemical similarity of copper, nickel, and cobalt. Separation and purification of copper and nickel by selective extraction with organic compounds (liquid ion exchange reagents) is currently practiced in the extractive metallurgy of copper and nickel. However, in these cases the aqueous solutions contain primarily one metal, the others being treated as impurities, not products. Cobalt recovery from precipitated mixtures of nickel and cobalt sulfides derived from laterites is also currently practiced. The details of the procedures used to purify the leach solutions prior to reduction, however, would differ somewhat from those used for nodules because of the differences in amount and content of impurities. The generation of producer gases from coal (or oil) for the reduction of nodules and all other plant services represent the utilization of known technology essentially without adaptation. The detailed design bases used in developing the process description used are summarized in the criteria sheets in Volume III.

While many variations are possible, particularly with respect to equipment types, for the basic scheme proposed for smelting, little information is available to suggest that substantially different approaches would be more advantageous. Alternative routes to the recovery of copper, nickel, and cobalt from the matte, or even the unsulfidized alloy, are technically feasible. However, the route chosen attempts to make maximum use of elements of existing technology, and variations are not likely to have major impacts on the overall plant inputs and outputs. The production of fertilizer grade ammonium sulfate from metal-free liquors would be a realistic alternative to lime boiling for ammonia recovery, and would involve buying make-up ammonia instead of lime, with a reduction in the amount of solid wastes (gypsum) produced.

8.3 PLANT INPUTS AND OUTPUTS

The major items which comprise the material and energy balances for the smelting process are summarized in Table 8.1. Included are production rates for the saleable products, consumption rates for major materials and supplies, raw materials requirements and a breakdown of the amounts of solid, liquid and gaseous wastes and the requirements for fuels and purchased power.

TABLE 8.1

MAJOR PLANT INPUTS AND OUTPUTS

MAJOR INPUTS

Nodules	1.41 x 10^6 mtpy	1.25 x 10^6 tpy
Coal & Coke	300 x 10^3 mtpy	330 x 10^3 tpy
Water	2.7 x 10^6 m^3/yr	703 x 10^6 gpy
Fuel Oil	25 x 10^3 m^3/yr	6.6 x 10^6 gpy
Oxygen	66.1 x 10^3 mtpy	72.6 x 10^3 tpy
Gases	5.2 x 10^3 mtpy	5.7 x 10^3 tpy
Liquids	13.8 x 10^3 m^3/yr	3.65 x 10^6 gpy
Solids	330 x 10^3 mtpy	363 x 10^3 tpy
Purchased Power	70.3 MW	

MAJOR OUTPUTS

Solid Wastes	691 x 10^3 mtpy	759 x 10^3 tpy
Liquid Wastes	0.84 x 10^6 m^3/yr	221 x 10^6 gpy
Stacked Offgases	15.3 x 10^3 m^3/min	541 x 10^3 scfm
Low Level Emissions	2.89 x 10^3 m^3/min	102 x 10^3 scfm
Cooling Tower Evaporation	2.4 x 10^3 m^3/min	84 x 10^3 scfm
Copper	7.81 x 10^3 mtpy	8.58 x 10^3 tpy
Nickel	10.2 x 10^3 mtpy	11.2 x 10^3 tpy
Cobalt	1.5 x 10^3 mtpy	1.65 x 10^3 tpy
Ferromanganese	228 x 10^3 mtpy	251 x 10^3 tpy

The distribution of services required within the plant is summarized on Table 8.2. The services include process power, process steam, cooling water and process water.

The composition of the output streams which constitute process wastes is summarized on Tables 8.3 and 8.4 for the solid and liquid and gaseous wastes, respectively. These compositions were derived from the overall plant material balance and are presented for only the major

TABLE 8.2

SERVICES PROFILE

	Process Power	Process Steam		Cooling Water		Process Water	
	kW	kg/hr x 10^3	pph x 10^3	m^3/min	gpm	m^3/min	gpm
Ore Preparation and Drying	1,500	-	-	-	-	-	-
Reduction	200	(9.5 x 10^6 kcal/hr)$^{(2)}$		-	-	-	-
Smelting	750	(3.5 x 10^6 kcal/hr)$^{(2)}$		8.0	2,100	-	-
	23,900	-	-				
Converting	450	(14.5 x 10^6 kcal/hr)$^{(2)}$		-	-	-	-
Ferromanganese Production	1,050	(18 x 10^6 kcal/hr)$^{(2)}$		9.5	2,500	-	-
	50,700	-	-				
Leaching	500	0.9	2	4.5	1,200	0.6	151
pH Adjustment	100	-	-	0.6	150	-	-
Copper LIX	100	0.6	1.3	0.5	135	-	-
Copper Electrowinning	2,850	1.0	2.3	-	-	0.021	5.5
Neutralization	50	-	-	-	-	0.003	0.7
Nickel LIX	150	1,8	3.9	0.5	140	0.019	5
Nickel Electrowinning	5,000	1.3	2.9	-	-	0.028	7.3
Cobalt Recovery	300	3.4	7.5	2.1	550	-	-
Ammonia Recovery	150	9.1	20	9.1	2,400	0.10	27
Waste Treatment	700	-	-	-	-	0.55	144
Services & Materials Handling	4,400	31.3	69	76.5	20,200	2.8	740
	(22,200)$^{(1)}$	(113)$^{(3)}$	(240)$^{(3)}$				3,720
TOTAL	70,300	49.4	109	111$^{(4)}$	29,400$^{(4)}$	4.1$^{(5)}$	1,080$^{(5)}$

(1) Generated internally.

(2) Generated in waste heat boilers for power.

(3) Used internally in power generation, main and waste heat boilers.

(4) 250 x 10^6 Btu/hr (non consumptive use).

(5) Consumptive use.

TABLE 8.3

CHARACTERIZATION OF SOLID AND LIQUID WASTES

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHED TAILS & GYPSUM	NEUTR. pptd SOLIDS	LIME BOIL SOLIDS	GRANU-LATED SLAG	GASIFICA-TION ASH (Slag)	COMBUS-TION ASH	WATER HARDNESS SOLIDS	OFFGAS SCRUBBER SOLIDS	SMELTING DUST
Solid Flows	mtpd	0.33	0.05	0.11	20	9	190	1600	39	13	2.5	26	0.174
	tpd	0.36	0.06	0.12	22	10	210	1760	43	14	2.7	29	0.191
Liquid Flows	m^3/hr				1.1	1.5	5.5	17	17		0.3	4.6	
	gpm				5	6.8	24	73	75		1.5	20	
Temperature $^{o}C/^{o}F$		25/77	25/77	25/77	50/132	40/104	50/132	40/104	80/176	90/194	25/77	75/165	[illegible]
Constituents:		. Lead . Lead Sulfate . Etc	. UNK	. Carbon	. Gypsum . Silica . Aluminum Oxide . Copper Sulfide . Sulfuric Acid . Nickel . Iron . Cobalt . Nickel Sulfide . Copper	. Iron Hydroxide . Magnesium Hydroxide . Manganese Hydroxide . Copper . Nickel . Cobalt . Ammonia	. Gypsum . Silica . Aluminum Oxide . Copper . Nickel . Cobalt . Magnesium . Sodium . Boric Acid . Ammonium	. Manganese Oxide . Magnesium . Manganese . Sodium . Iron Oxide . Boric Acid . Aluminum Oxide . Calcium Oxide . Sulfuric Acid . Silica . Copper . Nickel	. Silica . Aluminum Oxide . Etc	. Silica . Limestone . Aluminum Oxide . Etc	. Limestone . Silica . Aluminum Oxide . Etc	. Calcium Sulfate . Carbon Sulfite . Silica . Aluminum Oxide . Manganese Oxide . Manganese Dioxide	. Manganese Oxide . Manganese . Iron . Iron Oxide . Zinc . Lead . Etc
Chemical Characteristics:		A			A, D	A, D	A, D	A, D, E	A,B,D,E	A, B	B, E	A,B,D,E	A
Physical Characteristics:		D			B	A, B	B	C	C		B	B	D

KEY:

CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS	
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 8.4

COMPOSITION OF GASEOUS EFFLUENT STREAMS

STREAM		DUST CONTROL EXHAUST	TANK HOUSE EXHAUST[(1)]	TANK HOUSE EXHAUST	DRYER OFFGAS	FUGITIVES CONTROL EXHAUST	LEACH VENTS	PROCESS VENT	CONVERTER, GRANULATION GAS	REDUCING GASES TO BOILER	PRODUCER GAS	STACKED GASES
Total Flow	m^3/min	1,425	42		2,610	7,080	58	28	764	1,950	1,240	15,100
	scfm	51,000	1,500	1,890	92,200	250,000	2,100	1,000	27,000	69,000	44,000	541,000
Temp.	°C	25	50	50	175	55	40	35	40	325	925	145
	°F	77	122	122	347	131	104	95	104	617	1,697	293
Press, atmospheres		1	1	1	1.05	1	1	1	1.1	1.1	1.7	1
% Oxygen		21	7	7.5	10	21	16	17	20	3.9	--	12.3
Nitrogen		79			58	79	77	66	79	47.5	49	64.5
Ammonia											0.2	TR
Carbon Monocide						TR				13.1	18	TR
Carbon Dioxide					5	TR		10	1	22.8	8	5
Methane											4	
Hydrogen				0.5							9	
Water			93	92	27		7	7		12.4	11	18.2
Hydrogen Sulfide, Sulfur Dioxide					0.03	TR				0.3	0.4	TR

---

(1) Cell exhaust only, excluding building ventilation.

materials in the process. Where trace amounts of a material are indicated, it has been assumed that previous removal steps will have reduced it to a level which is either acceptable for discharge directly or it is present in amounts too low to quantify within the accuracy of the methods used in this study.

As shown in Table 8.3 a substantial portion of the solid wastes will be in the form of vitreous slag rather than a slurry. This slag material would be chemically and physically inert and stable. The slag could have value as a saleable byproduct for use as aggregate or fill material. Therefore in this process alone a substantial portion of the wastes would not require containment in a sealed tailings disposal site and may have some value. Either way the waste disposal problems associated with the smelting process should be less than for any other process.

A summary of the flows and distributions of potentially toxic elements for the smelting process is presented in Table 8.5. A sizeable proportion of the potentially toxic elements report to the slag. As with the toxic elements which report to the products the toxic elements in the slag are not of concern because they are not in a chemically toxic form. Only silver, arsenic and antimony report to the tailings and these would be in chemically stable compounds which are not toxic. As in other processes the tailings can be safely stored in a lined tailings containment facility.

TABLE 8.5

DISTRIBUTION OF POTENTIALLY TOXIC ELEMENTS

Element	Input Rate To Plant kg/day	(lbs/day)	Distribution As Percent Reporting To Slag	Tailings	Products
Barium	10,000	22,000	100	0	0
Lanthanum	4,000	8,800	100	0	0
Vanadium	1,000	2,200	54	1	45
Chromium	30	66	55	0	45
Silver	8.2	18	0	55	45
Cadmium	50	110	45	3	52
Arsenic	132	290	10	19	71
Antimony	77	170	0	95	5
Thallium	500	1,100	45	4	51
Lead	1,320	2,900	45	5	50

8.4 PLANT RESOURCE REQUIREMENTS

It is estimated that the total plant facility, including processing and support facilities but excluding long term waste containment areas, will require approximately 50 hectares (120 acres) of land. Within the hydrometallurgical processing area, the plant layout will involve equipment densities which are typical for both the nonferrous metals and the chemical processing industries. Separate processing buildings would be provided for the liquid ion exchange operation and for the smelting and converting sections as well as for copper and nickel electrowinning and cobalt recovery. Nodule drying and reduction, coal gasification, slag granulation and ammonia recovery would be outside installations. A boiler house/power house and banks of cooling towers would be located adjacent to the chemical process areas, and offices, laboratories, maintenance shops, warehouses, control houses, and a change house/cafeteria and parking area would also be located close to the main processing area. The aforementioned facilities would require about 12 to 20 hectares (30-50 acres) of land. In addition, a considerable area is required to provide materials storage. The nodules storage and decant ponds, the coal and coke, lime and limestone, silica and gypsum storage areas, and a plant run off and emergency waste storage area would require at least 20 hectares (50 acres), including margins, of relatively flat terrain. No unusually tall structures would be required in the process areas, but the main stack height could be significant, depending on local meteorological conditions.

The materials movements in and out of that plant are significant: excluding raw nodules and waste products, in excess of 2100 mtpd (2300 tpd) of fuels and process materials are brought in and 745 mtpd (825 tpd) of products are shipped out. Thus, the transportation network supporting plant operations must include highway and rail connections capable of supporting considerable traffic. The coal and coke, lime and limestone, silica and gypsum, ammonia and hydrogen sulfide, and sulfuric acid would be delivered and copper, nickel and ferromanganese would be shipped by rail. Most other materials and supplies would be trucked, except that oxygen would be purchased over-the-fence.

Manufacturing operations within the plant will be on a three shift, 365 day per year basis. It is estimated that about 300 people will be employed in the facility, including operating and maintenance labor, supervision, and plant general and administrative personnel. The mix of skill levels would be typical of a chemical processing plant, with about one third being skilled tradesmen and lead operators, one third unskilled laborers, and one third professional/management and clerical/support personnel.

The plant resource requirements, including energy and water requirements already presented in Section 8.3, are summarized in Table 8.6.

8.5 WASTE TREATMENT

The types of waste treatment which could rationally be carried out on the wastes from a process plant were described in Section 3.12. In this section the impact of treatment in terms of changes in the

TABLE 8.6

PLANT RESOURCE REQUIREMENTS

Item	Quantity
Land	50 hectares, 120 Acres
Manpower	300 Persons
Water	42 m^3/min, 1080 gpm
Energy	
Coal & Coke	820 mtpd, 900 tpd
Electricity	70.3 MW

material and energy balances for the smelting process are identified. These are presented in Table 8.7.

8.6 ACCIDENTAL RELEASE POTENTIAL

The inventory of potentially hazardous solids, liquids and gases which would be stored at the plant site or are "in-process" for the smelting process are summarized in Table 8.8.

TABLE 8.8

INVENTORY OF POTENTIALLY HAZARDOUS SUBSTANCES

Total Liquid	10,000 tonnes	(11,000 tons)
Sulfuric Acid	4,500 tonnes	(5,000 tons)
Ammonia	90 tonnes	(100 tons)
Chlorine	23 tonnes	(25 tons)
Hydrogen Sulfide	270 tonnes	(300 tons)
Fuels	4,500 tonnes	(5,000 tons)

The hazards summary for accidental releases of the items inventoried for this process are summarized in Table 8.9.

TABLE 8.9

HAZARDS SUMMARY

Metal Dust - 10^{-1} Per Year
Acid Mist - 10^{-4} Per Year
Large Gas Release - 10^{-5} Per Year
Ammonia - 500 mg/l (or ppm) (level of concern) to 10 km (6 Miles)
Hydrogen Sulfide - 50 mg/l (or ppm) (level of concern) to 11 km (7 Miles)
Chlorine - 50 mg/l (or ppm) (level of concern) to 5 km (3 Miles)

TABLE 8.7

WASTE TREATMENT IMPACT ON PLANT REQUIREMENTS

Materials/Services Required	Base Case		Treatment Method					
	pH Adjustment Only		Precipitate Toxic Elements Only		Precipitate Toxic Elements and Wash Solids		Precipitate Toxic Elements, Wash, and Dry Solids	
			ADDITIONAL MATERIALS/SERVICES REQUIRED					
Coal, mtpy x 10^3 (tpy x 10^3)	219	(241)	12.5	(13.7)	19	(21)	103	(113.5)
Lime, mtpy x 10^3 (tpy x 10^3)	26	(29)			12.5	(13.7)	12.5	(13.7)
Limestone, mtpy x 10^3 (tpy x 10^3)	14	(15)			0.66	(0.73)	3.6	(3.9)
Sorbent, mtpy x 10^3 (tpy x 10^3)		0			0.36	(0.40)	0.36	(0.4)
HCl (37%), mtpy (tpy)		0			156	(172)	156	(172)
Flocculants, mtpy x 10^3 (tpy x 10^3)	64	(70)			0.24	(0.26)	0.24	(0.26)
Water, m^3/yr x 10^6 (gpy x 10^6)	2.7	(703)			0.19	(50.4)	0.21	(55.0)
Power, kWh x 10^6	562		0.4		4.0		4.8	
Wastes Produced			ADDITIONAL WASTES PRODUCED					
Stacked gases, m^3/min x 10^3 (scfm x 10^3)	15.1	(541)			0.37	(13.2)	4.0	(140.5)
Cooling tower evaporation, m^3/min x 10^3 (scfm x 10^3)	2.4	(84)			0.41	(14.4)	0.44	(15.5)
Solid wastes, mtpy x 10^3 (tpy x 10^3)	690	(758)	26.8	(29.5)	29.0	(31.9)	39.7	(43.6)
Liquid wastes, m^3/yr x 10^6 (gpy x 10^6)	0.85	(224)			0.03	(6.9)	0.04	(10.5)

Except for the metal dust exposure potential, this process is similar to the high temperature sulfuric acid process. Since, however, the volumes of toxic gases in storage are about 1/3 of those for the high temperature sulfuric acid plant, the range over which a given concentration level might be expected is reduced.

The smelting process normally generates metallic dusts which are discharged as particulates. These are only considered toxic for long-term exposures. These emissions would only occur when the precipitators are broken down and long-term exposure is unlikely.

8.7 NOISE ASSESSMENT

The basis upon which this noise assessment was developed is discussed in Section 3.13. The noise level at the plant boundary is estimated at between 52 and 62 dBA. This noise level is shown graphically on Figure 8.3. This level corresponds to the noise that would be generated in a typical large store accounting office.

TYPICAL A-WEIGHTED SOUND LEVELS

At a Given Distance From Noise Source	Decibels RE: 20 N/m^2	Environmental
	140	
50 HP SIREN (100 FT)		
	130	
JET TAKEOFF (200 FT)		
	120	
RIVETING MACHINE	110	CASTING SHAKEOUT AREA
CUTOFF SAW		
PNEUMATIC PEEN HAMMER	100	ELECTRIC FURNACE AREA
TEXTILE WEAVING PLANT		
SUBWAY TRAIN (20 FT)	90	BOILER ROOM
		PRINTING PRESS PLANT
PNEUMATIC DRILL (50FT)		
	80	TABULATING ROOM
		INSIDE SPORT CAR (50 MPH)
FREIGHT TRAIN (100 FT)		
VACUUM CLEANER (10 FT)	70	
SPEECH (1 FT)		
		NEAR FREEWAY (AUTO TRAFFIC)
	60	LARGE STORE
SMELTING PROCESS		ACCOUNTING OFFICE
LARGE TRANSFORMER (200 FT)		PRIVATE BUSINESS OFFICE
	50	LIGHT TRAFFIC (100 FT)
		AVERAGE RESIDENCE
		MIN LEVELS RESIDENTIAL AREAS
	40	IN CHICAGO AT NIGHT
SOFT WHISPER (5 FT)		
	30	STUDIO (SPEECH)
	20	STUDIO FOR SOUND PICTURES
	10	
THRESHOLD OF HEARING		
YOUTHS 1000-4000 Hz	0	

FIGURE 8.3 ESTIMATED NOISE LEVEL AT PLANT BOUNDARY

9.0 AT-SEA PROCESSING

9.1 RATIONALE FOR AT-SEA PROCESSING

It is possible that the overall economics and problems of land-based nodules processing and waste disposal will be such that at-sea processing will become attractive. If at-sea technology is developed and implemented, it will have significant bearing on the impacts of those processing operations, if any, which remain to be carried out in land-based plants.

There are two main incentives which may stimulate processing or preprocessing nodules at the mine site, i.e., at sea. The first is the savings in transportation costs which will accrue if a more concentrated product could be shipped to a land plant. The second incentive is the cost of waste disposal for land-based processing plants. The costs of disposal of process wastes, in amounts approximately equal to the tonnage of nodules input to the plant, will be significant. In fact, problems associated with the disposal of the large amounts of wastes generated from treatment of raw nodules might ultimately constrain the development of the industry by dictating where processing plants can be located.

9.2 PROCESS POSSIBILITIES FOR AT-SEA TREATMENT

Broadly, three classes of treatment schemes might be attempted for preprocessing or processing nodules at sea. They are:

A minimum treatment to upgrade nodules by physical means (beneficiation).

Partial treatment of nodules by chemical and physical means to produce an intermediate product whose volume is less than that of raw nodules.

Complete at-sea treatment to produce finished metal products.

9.2.1 Physical Beneficiation

If the nodules mineralogy permitted carrying out a physical beneficiation operation at sea, it would probably be economically attractive. A low-grade tailings would be rejected at sea as waste and the product would be an upgraded nodule material which would be shipped to land-based plants for further processing. Unfortunately, it has been repeatedly demonstrated that the nodules are not amenable to such physical beneficiation, and at least some chemical processing would be required to liberate the valuable metals from the nodule's matrix.

9.2.2 Partial Processing

Several schemes can be conceived which fall within this category. For instance, the nodules might be partially reduced to form a dispersed metallic phase containing the copper, nickel, cobalt and iron which would then be separated from the bulk of the manganese residue by magnetic separation. Alternatively, the nodules could be reduced, if required, and/or leached directly to dissolve the value metals in concentrated leach liquors. These could be separated from leach residues and the residues would then be discarded at sea. The leach liquors (acidic or basic solutions containing metal values) could be shipped directly to a land-based plant or treated further at sea.

9.2.3 Metal Production

Further treatment might involve reduction of the metal values from solution, either separately to produce fairly pure metals individually, or in a single step that would produce a mixture of metals which would require further refining.

The sequence of steps which would involve reduction, leaching, separation of solution from residues and separation of metal values prior to reduction from solution is, in fact, the sequence of operations which occurs in land-based plants and represents complete treatment of nodules at sea.

9.3 TECHNOLOGICAL CONSTRAINTS

To be consistent with the study assumptions used as the basis for evaluations of other aspects of nodules processing, the analysis of the possibility of at-sea processing will be restricted to processes for which a technology base exists and for which some information is available. Specifically, only those processes already identified as being most likely to be used in land based plants will be considered. With sufficient development effort, additional options probably could be developed for at-sea processing which would significantly affect economics and increase the likelihood of this approach being utilized.

9.3.1 At-Sea Constraints

The installation of a processing plant, or any element of that plant, in a sea-going vessel will subject the equipment to some motion. This is the principal difference from a land-based plant. Operations or equipment which would be most affected by vessel motions are smelting, electrowinning, decanting, rake classification, leach thickeners, stripping and scrubbing tanks, furnaces and converters, extraction tanks and possibly fluidized bed reactors.

9.3.2 Physical Treatment Constraints

Reducing the size of nodules prior to transfer from the mining ship would be desirable to facilitate slurry handling systems. The equipment needed for beneficiation at sea would be the same as that in land based plants and could provide all the size reduction necessary for shore or at-sea process plants. Only a few hundred tons of equipment, plus in-process material, would have to be added to the mining ship. Relatively small amounts of electrical power, which could be easily handled by the mining ship, would also be required.

Another possible treatment, the drying of the ground nodules, could be accomplished on the mining ship in the same manner as for on-land process plants. More fuel for hot combustion gas drying would be needed. Drying is eventually required for all processes, except the high-temperature sulfuric acid and cuprion processes which utilize wet fines as feed.

None of these treatment methods are practical for installation on transport vessels or barges. These vessels would have much less time to accomplish the treatment since the treatment could only be performed while the transport vessel is steaming to port and not continually as on the mining vessel. Also, all of the transport vessels would have to be equipped, which would entail much higher equipment costs. Therefore, treatment at sea would probably either be done on the mining ship or not at all.

9.3.3 Processing Constraints

In the land-based process routes, all value metals are dissolved in the pregnant liquor from leaching operations and must be selectively removed (separated) to permit the direct production of marketable metals. These operations are normally carried out in conventional mixer-settler units. These units depend on gravity and the operation would be adversely affected by fluid motions induced by the pitching and rolling of the processing vessel, even if the degree of motion were quite small. Therefore, units of conventional design may not perform adequately in this environment. Two available alternatives to the use of conventional mixer-settlers would alleviate this problem. One alternative involves the use of coalescers, which greatly reduce the size of the separators and might permit separation to take place if pitch and roll are not severe. These units have not been demonstrated under at-sea conditions however, and are not in general use in land-based plants. A second alternative involves the use of solid ion exchange resins. Since metals are loaded and extracted alternately from single fluid phases, the separation problem would not exist. However, solid ion exchange technology is not used on land-based plants because of the high costs involved and their use at sea would be subject to the same limitation.

Even if adequate ion exchange separation technology could be developed, problems would still occur in the metal reduction step. The operation of a conventional electrowinning tank house on seagoing vessels would be difficult because of the problems associated with vessel motion. A modification of the conventional cell design can be envisioned to permit anodes and cathodes to be stabilized against the ship's motion. However, this would require the development of new technology.

As an alternative to complete treatment to produce metals of cathode specification, the pregnant liquors might be treated to reduce selectively or totally the value metals with the production of materials which would require further refining on land. Such an approach, however, would involve the transport of a large amount of reductant from land to the processing facility. Thus, transportation cost savings which would result from shipping highly concentrated, impure metal precipitates would be partially offset by the costs of transporting reductants.

An alternative to reduction at sea is to transport the pregnant liquors produced at sea to land-based plants for metal separation and reduction. However, with the exception of the reduction/hydrochloric acid leach and smelting processes, the pregnant liquors produced in the hydrometallurgical portions of the processes are very diluted. Thus, except for the fact that the shipment of clear solutions would be somewhat easier than the shipment of nodules slurries, savings would be unlikely in transportation costs for this approach.

An at-sea smelting route offers a potentially significant advantage in both transportation and waste disposal costs in that the metallic phase produced in the first smelting step is very highly concentrated in copper, nickel and cobalt, amounting to less than 3 percent of the original nodules weight. However, severe technological problems exist in attempting to carry out smelting operations at sea. These problems arise because the smelting operation depends upon gravity to effect phase separations. Since little has been published about the physical properties of slags which would be produced in manganese processing,and since significant technical and safety problems are anticipated in attempting to carry out a smelting operation at sea given the expected vessel motion, the smelting route is not a likely candidate for at-sea processing at this time and is not considered further.

In summary, complete at-sea processing of nodules would require the development of new technology, particularly in the areas of metal separation by ion exchange and in metal reduction by electrowinning. While at-sea use of a smelting route is not likely, preprocessing at sea to produce either pregnant liquors which would be shipped to land-based plants for further processing or for the production of impure, mixed metal precipitates is possible. Both approaches would offer the potential of reducing the land-based waste treatment costs, but a careful economic analysis would be required to determine the relative savings in transportation and processing costs for each route. At-sea production of a mixed metal precipitate will greatly reduce sea-to-land transportation costs, but would increase land-based metal processing costs relative to a scheme which involved shipment of pregnant liquors to land plants for metals separation and selective reduction. Shipment of relatively dilute pregnant liquors to a land plant is not likely to reduce transportation costs, but the processing sequence would be relatively simple.

9.4 SELECTION AND DESCRIPTION OF POSSIBLE AT-SEA PROCESSING SCHEMES

9.4.1 General

Based on the rationale developed in Section 9.3, those portions of the Reduction/Ammonia Leach, High Temperature Sulfuric Acid Leach, Reduction/Hydrochloric Acid Leach and Cuprion/Ammoniacal Leach process flow sheets considered potentially adaptable for use at sea were defined. The modified processes are shown in Figures 9-1 through 9-4 which are, essentially, altered versions of the flow sheets for land-based plants with pregnant liquor produced at sea and processed on land. The portion of the process conducted at-sea is shown in the shaded area. The land portion is unshaded. Where a function is performed both on land and at sea it is shown by a line splitting the function.

The processes would be modified slightly both at sea and on land for cases in which metal mixtures are reduced from solution at sea. Equipment requirements and sizes were estimated from information contained in the detailed flow sheet and line tables and the criteria summary sheets. The list of major equipment units, number of units required and approximate size of each unit onboard the sea process plant for each possible at-sea process is contained in Volume III of this report.

In the following sections those processing areas which would be located at sea and on land are summarized and the sea-land material movements are identified. Accompanying tables summarize the at-sea processing service requirements. The characteristics of the process vessels required for at-sea partial processing and transportation fleet requirements are presented in Section 9.5. The characteristics of the land based plants required to produce marketable products from the outputs of at-sea partial process plants are presented in Section 9.6 for all process options considered.

Equipment requirements differ slightly from the detailed land plant process flow sheets. The ammonia leach thickeners are replaced by centrifuges. The tailings washings are performed by banks of mechanical centrifuges with intermediate surge tanks in all processes. In the sulfuric acid and cuprion processes, the rake classifiers are replaced by two banks of cyclones and the counter-current decanting operation is replaced with trains of five centrifuges alternating with surge tanks.

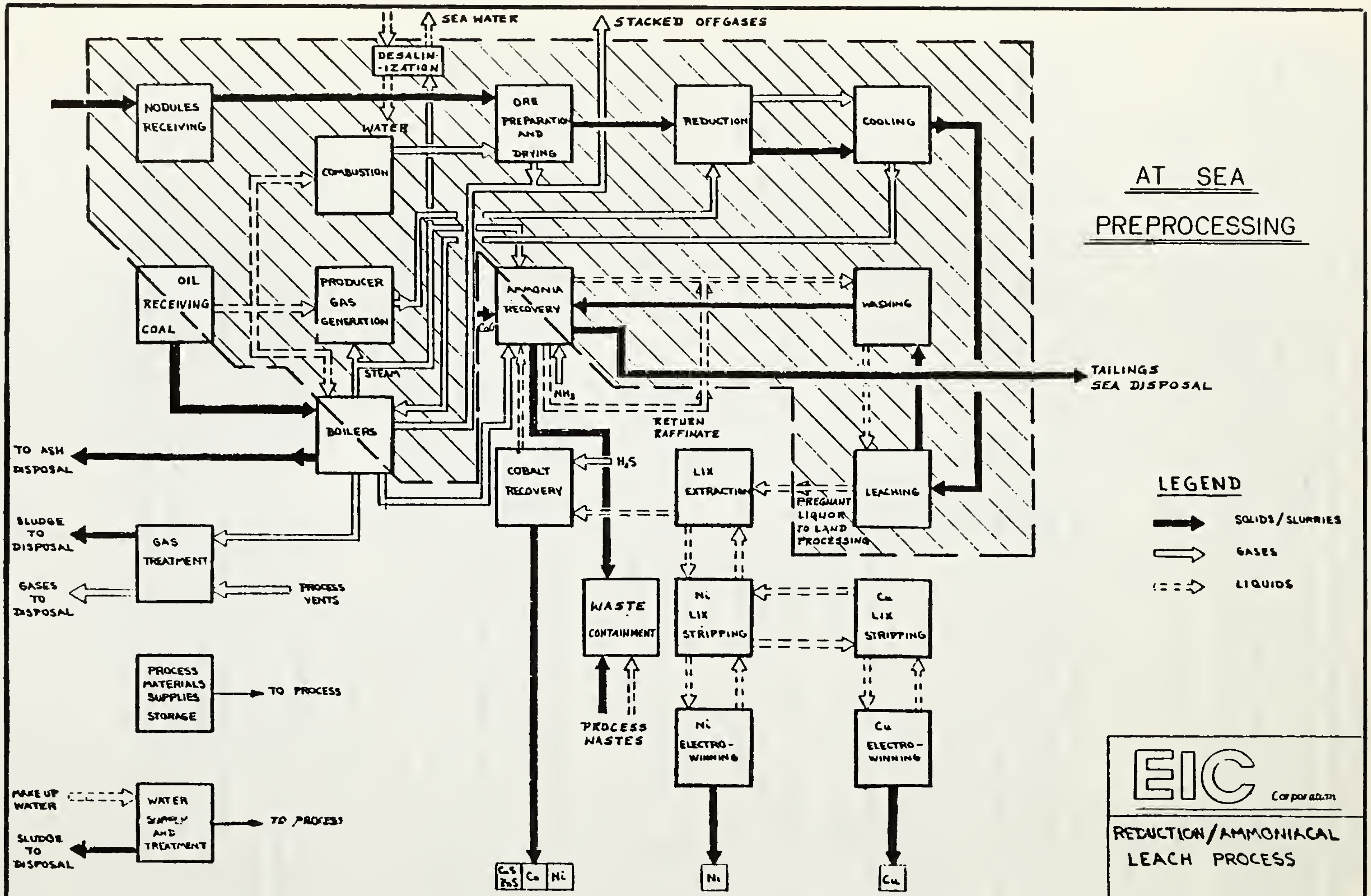


FIGURE 9.1

LAND PLANT

EIC Corporation

REDUCTION/AMMONIACAL LEACH PROCESS

PROCESS OUTLINES
AT SEA PREPROCESSING

NC-0014-AM
REV. 0

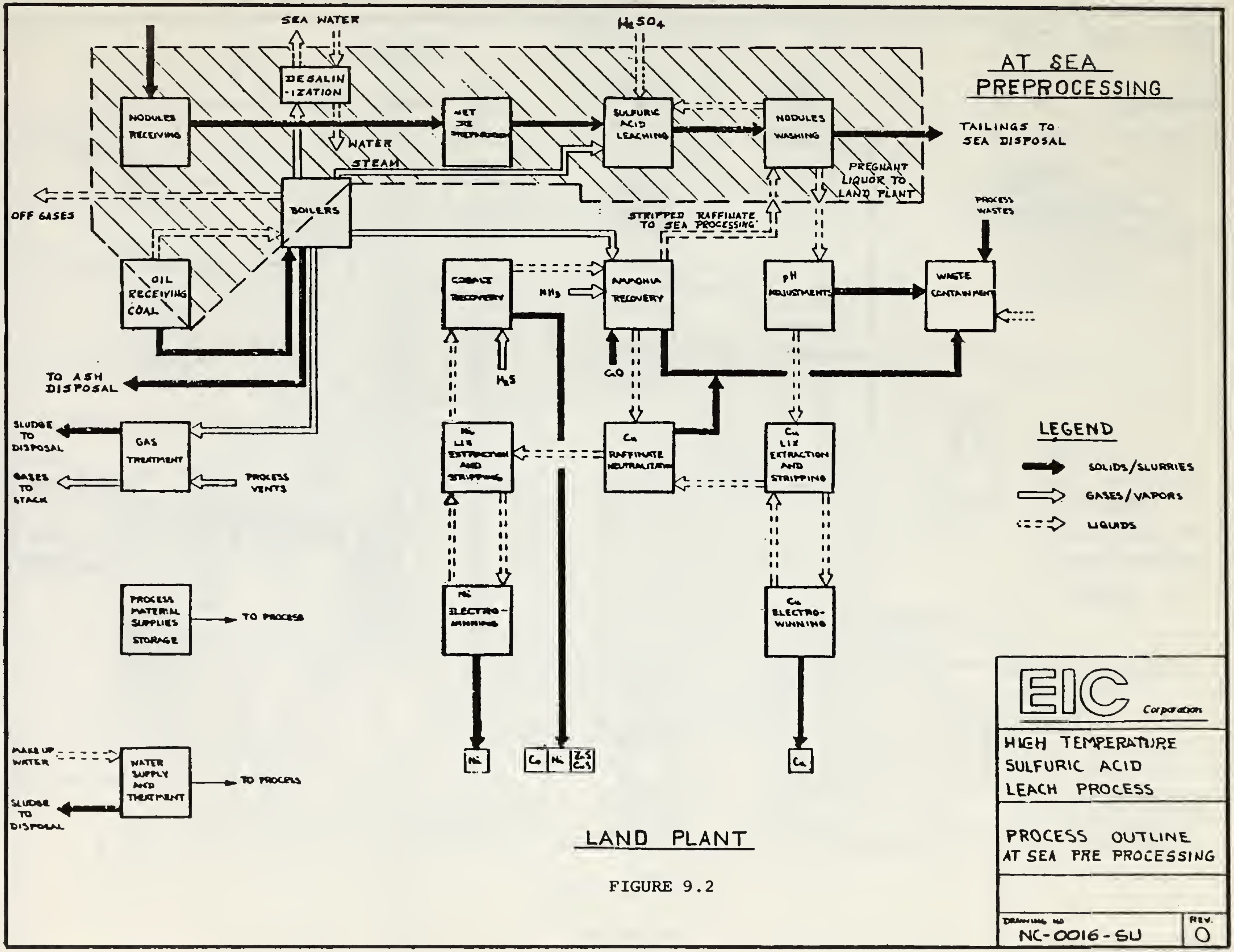

AT SEA PREPROCESSING
SEA WATER
DESALIN-IZATION
H_2SO_4
NODULES RECEIVING
WET ORE PREPARATION
SULFURIC ACID LEACHING
NODULES WASHING
TAILINGS TO SEA DISPOSAL
WATER
STEAM
BOILERS
OFF GASES
OIL RECEIVING COAL
PREGNANT LIQUOR TO LAND PLANT
STRIPPED RAFFINATE TO SEA PROCESSING
PROCESS WASTES
COBALT RECOVERY
NH_3
AMMONIA RECOVERY
pH ADJUSTMENTS
WASTE CONTAINMENT
H_2S
CaO
TO ASH DISPOSAL
SLUDGE TO DISPOSAL
GAS TREATMENT
GASES TO STACK
PROCESS VENTS
Ni LIX EXTRACTION AND STRIPPING
Cu RAFFINATE NEUTRALIZATION
Cu LIX EXTRACTION AND STRIPPING
Ni ELECTRO-WINNING
Cu ELECTRO-WINNING
PROCESS MATERIAL SUPPLIES STORAGE
TO PROCESS
MAKE UP WATER
WATER SUPPLY AND TREATMENT
TO PROCESS
SLUDGE TO DISPOSAL
Ni
Co
Ni
ZS
CuS
Cu
LAND PLANT
LEGEND
SOLIDS/SLURRIES
GASES/VAPORS
LIQUIDS
EIC Corporation
HIGH TEMPERATURE SULFURIC ACID LEACH PROCESS
PROCESS OUTLINE AT SEA PRE PROCESSING
DRAWING NO
NC-0016-SU
REV.
0

FIGURE 9.2

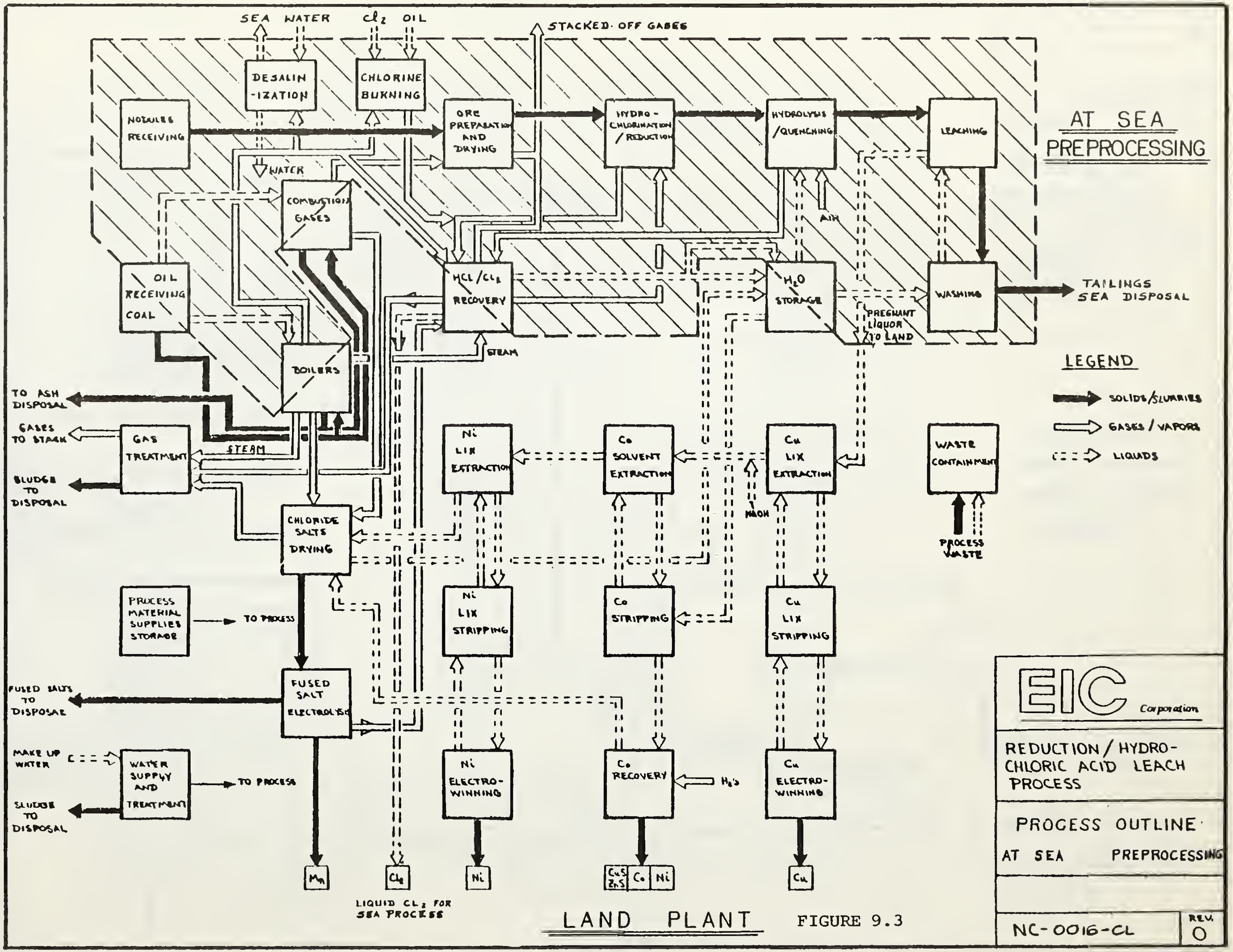

AT SEA PREPROCESSING
SEA WATER
Cl_2
OIL
STACKED-OFF GASES
DESALIN-IZATION
CHLORINE BURNING
NODULES RECEIVING
ORE PREPARATION AND DRYING
HYDRO-CHLORINATION / REDUCTION
HYDROLYSIS /QUENCHING
LEACHING
WATER
COMBUSTION GASES
AIR
OIL RECEIVING COAL
HCL/CL_2 RECOVERY
H_2O STORAGE
WASHING
TAILINGS SEA DISPOSAL
PREGNANT LIQUOR TO LAND
STEAM
BOILERS
TO ASH DISPOSAL
GASES TO STACK
GAS TREATMENT
STEAM
SLUDGE TO DISPOSAL
LEGEND
SOLIDS/SLURRIES
GASES / VAPORS
LIQUIDS
Ni LIX EXTRACTION
Co SOLVENT EXTRACTION
Cu LIX EXTRACTION
WASTE CONTAINMENT
PROCESS WASTE
NaOH
CHLORIDE SALTS DRYING
Ni LIX STRIPPING
Co STRIPPING
Cu LIX STRIPPING
PROCESS MATERIAL SUPPLIES STORAGE
TO PROCESS
FUSED SALT ELECTROLYSIS
FUSED SALTS TO DISPOSAL
MAKE UP WATER
WATER SUPPLY AND TREATMENT
TO PROCESS
SLUDGE TO DISPOSAL
Ni ELECTRO-WINNING
Co RECOVERY
H_2S
Cu ELECTRO-WINNING
Mn
Cl_2
Ni
CuS ZnS
Co
Ni
Cu
LIQUID CL_2 FOR SEA PROCESS
LAND PLANT
EIC Corporation
REDUCTION / HYDRO-CHLORIC ACID LEACH PROCESS
PROCESS OUTLINE
AT SEA PREPROCESSING
NC-0016-CL
REV. 0

FIGURE 9.3

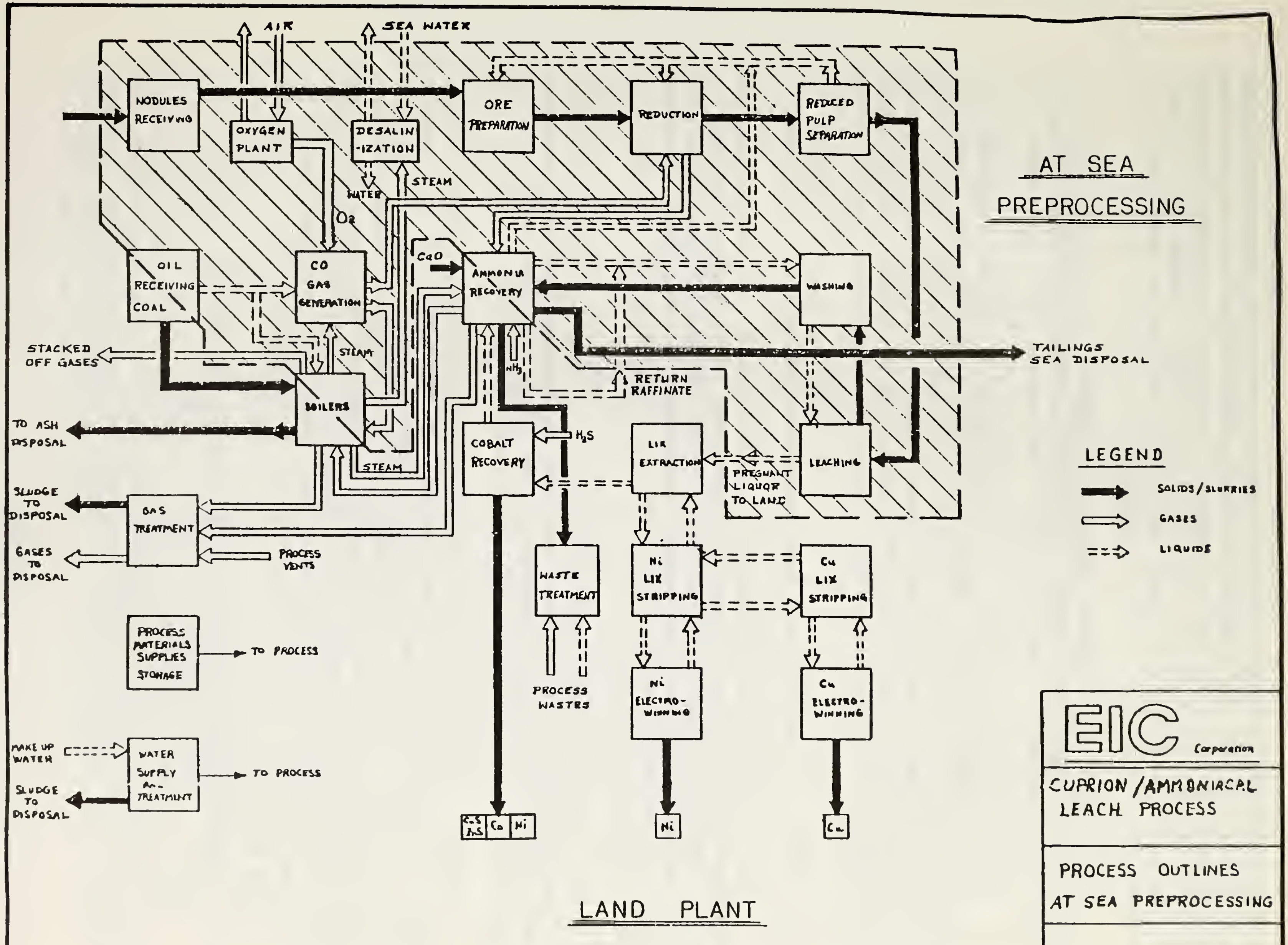

AIR
SEA WATER
NODULES RECEIVING
OXYGEN PLANT
DESALIN-IZATION
WATER
STEAM
O2
ORE PREPARATION
REDUCTION
REDUCED PULP SEPARATION
AT SEA PREPROCESSING
OIL RECEIVING COAL
CO GAS GENERATION
CaO
AMMONIA RECOVERY
WASHING
TAILINGS SEA DISPOSAL
STACKED OFF GASES
STEAM
NH3
RETURN RAFFINATE
BOILERS
TO ASH DISPOSAL
COBALT RECOVERY
H2S
LIX EXTRACTION
PREGNANT LIQUOR TO LAND
LEACHING
STEAM
SLUDGE TO DISPOSAL
GAS TREATMENT
GASES TO DISPOSAL
PROCESS VENTS
WASTE TREATMENT
PROCESS WASTES
Ni LIX STRIPPING
Cu LIX STRIPPING
Ni ELECTRO-WINNING
Cu ELECTRO-WINNING
PROCESS MATERIALS SUPPLIES STORAGE
TO PROCESS
MAKE UP WATER
WATER SUPPLY AND TREATMENT
TO PROCESS
SLUDGE TO DISPOSAL
CuS ZnS
Co
Ni
Ni
Cu
LAND PLANT
LEGEND
SOLIDS/SLURRIES
GASES
LIQUIDS
EIC Corporation
CUPRION/AMMONIACAL LEACH PROCESS
PROCESS OUTLINES AT SEA PREPROCESSING
NC-0014-CU
REV.

FIGURE 9.4

The equipment units noted above perform the same function as the units listed on the original flow sheets but are better suited for use at sea either because of reduced size or adaptability for use where the operation will be subjected to motion. The lists of equipment does not include boilers, distillers, electrical generators, tankage requirements in the hull, nor pumps, piping, and vents and similar small ancillary equipment.

Certain nodule treatment steps are assumed to be carried out on the mining ship prior to transfer to the processing vessel, specifically, removal of sediment, mud and other fine wastes and size reduction.

Drying of process feed, i.e., ground nodules, is required for the Reduction/Ammonia Leach and Hydrochloric Acid processes. For the purpose of this evaluation, drying is assumed to take place on the processing vessel since, in part, waste heat can be utilized for other on-board operation. It is assumed that slurried ground nodules would be pumped to the processing vessel and, after dewatering, fed directly into a dryer.

9.4.2 Reduction/Ammonia Leach Partial Process Options

The at-sea Reduction/Ammonia Leach Process for the production of pregnant liquor (see Figure 9.1) includes: ore preparation; reduction, cooling, leaching and washing of the nodules; steam, power and producer gas generation and ammonia recovery. In addition, desalinization of sea water by distillation has been provided, and coal fuel has been replaced by fuel oil.

The pregnant liquor is transported to shore for LIX extraction, stripping, nickel and copper electrowinning, and cobalt recovery. Ammonia recovery is also necessary on-shore, and the raffinate is returned to the at-sea portion of the process plant.

Table 9.1 summarizes the requirements for services including power, steam, cooling water and process water for the production of pregnant liquor at sea by the Reduction/Ammonia Leach process. If the pregnant liquor produced in the at sea plant is steam stripped to remove ammonia, the value metals will be precipitated as a mixed basic metal carbonate (BMC). This could be removed from the liquor by centrifuging and sent to shore for further processing while the metal free solution would be recycled on board. The services for BMC production are also summarized in Table 9.1.

9.4.3 High Temperature Sulfuric Acid Leach Partial Process Options

This process, shown in Figure 9.2, is for the production of pregnant liquor and includes, in the at-sea process plants, the functions of wet ore preparation, sulfuric acid leaching, tailings washing and desalinization. If pregnant liquor is shipped to shore for metal removal, stripped raffinate, sulfuric acid and fuel are carried back out to the partial-process plant. The land plant performs the same metal extraction functions as described for the ammonia process system, except in a manner appropriate for an acid sulfate system.

TABLE 9.1

SERVICES PROFILE
REDUCTION/AMMONIA LEACH PARTIAL AT-SEA PROCESSING

	Power (kw)	Steam kg/hr x 10^3	Steam lb/hr x 10^3	Cooling Water m^3/min	Cooling Water gpm	Process Water m^3/min	Process Water gpm
(1)	18,400	182	401	104	27,400	4.9	1,300
(2)	19,800	305	671	206	54,400	10.3	2,730

Notes:
(1) Pregnant liquor production
(2) Base metal carbonate production

Table 9.2 summarizes the services require in the at-sea portion of this process for the production of pregnant liquor and a mixed metal sulfide. Reduction of impure metals from this pregnant liquor at sea is more difficult than for the ammonia based processes. Either hydrogen or hydrogen sulfide are the only practical reductants. The latter can be used at lower pH and pressure and gives high recoveries although its use on board ship presents obvious safety problems. While hydrogen might be purchased on land and shipped to the at-sea plant, a lower on board inventory would be required if sulfur and propane/butane (for hydrogen manufacture) were shipped out and hydrogen only made up on demand.

TABLE 9.2

SERVICES PROFILE
HIGH TEMPERATURE SULFURIC ACID LEACH PARTIAL AT-SEA PROCESSING

	Power (kW)	Steam kg/hr x 10^3	Steam lb/hr x 10^3	Cooling Water m^3/min	Cooling Water gpm	Process Water m^3/min	Process Water gpm
(1)	10,400	174	383	112	29,600	3.0	800
(2)	14,000	216	475	134	35,500	4.6	1,200

Notes:
(1) Pregnant liquor production
(2) Mixed metal sulfide production

In addition, limestone and lime would have to be shipped to the at-sea plant to neutralize the acidity formed in the precipitation reactions in order to allow the complete recovery of cobalt and nickel which process economics would require.

9.4.4 Reduction/Hydrochloric Acid Leach Partial Process Options

The at-sea portion of this process for the production of pregnant liquor is shown in Figure 9.3 and includes the ore preparation and drying, hydrochlorination and reduction, hydrolysis and quenching, leaching, washing, hydogen chloride and chlorine recovery, and washing elements of the land plant. In addition, desalination, and chlorine burning to produce hydogen chloride is added to replace the exchange, performed on land, with a separate plant.

The land plant includes metals separations and electrowinning sections plus chlorine salts drying and fused salt electrolysis to obtain manganese metal. Chlorine recovered in the land plant is liquified and shipped back to the sea plant. Only this process does not ship large volumes of raffinate back to the at-sea plant when producing a pregnant liquor at sea.

TABLE 9.3

SERVICES PROFILE
REDUCTION/HYDROCHLORIC ACID LEACH PARTIAL AT-SEA PROCESSING
PREGNANT LIQUOR PRODUCTION

	Steam		Cooling Water		Process Water	
Power (kW)	kg/hr x 10^3	lb/hr x 10^3	m^3/min	gpm	m^3/min	gpm
11,600	382	840	364	96,000	3.7	980

The pregnant liquor produced by this process is a very concentrated mixture of chloride salts of manganese, heavy metals, and alkali earth and alkali metals whose weight and volume are nearly equal to that of the raw nodules themselves.

It does not appear likely, however, that it will prove to be economically feasible to selectively reduce the value metals (manganese, copper, nickel, and cobalt) from this solution to reduce transportation costs still further.

9.4.5 Cuprion-Ammoniacal Leach Partial Process Options

The prospective at-sea and land partial process plants for the Cuprion process are shown in Figure 9.4 for the production of pregnant liquor at sea. Functions accomplished at sea include ore preparation and reduction, reduced pulp separation, leaching, washing, ammonia recovery, carbon monoxide gas generation, and oxygen and fresh water plants. Pregnant liquor is sent to shore, and the stripped raffinate returned. The shore plant is similar to the Reduction/Ammonia Leach process except that selective raffinate stripping is required to produce the high strength ammonia solution needed for reduction.

Table 9.4 presents the services profile for the Cuprion process at-sea plant for the production of pregnant liquor.

TABLE 9.4

SERVICES PROFILE
CUPRION/AMMONIACAL LEACH PARTIAL AT SEA PROCESSING

		Steam		Cooling Water		Process Water	
	Power (kW)	kg/hr $\times 10^3$	lb/hr $\times 10^3$	m^3/min	gpm	m^3/min	gpm
(1)	29,000	205	450	295	78,000	3.4	908
(2)	36,700	545	1200	553	146,000	8.6	2,270

Notes:
(1) Pregnant liquor production
(2) Basic metal carbonate production

As is the case for the Reduction/Ammonia Leach process, another option exists for at-sea processing. This option involves pregnant liquor stripping for the production of a basic metal carbonate cake (BMC) which would be shipped to shore for metals separation and recovery. The stripped liquors would be recycled at sea, but selective raffinate stripping operations would be done at sea to provide the required reduction liquor composition. This would be combined with BMC stripping. The services profile for the production of the BMC is also shown on Table 9.4.

9.5 PROCESSING VESSELS

The ship or barges on which a processing plant is installed will probably operate close to the mining ship. The processing vessel would need at least annual trips to port for repairs and refurbishment. This would probably be accomplished at the same time as the mining ship. With adequate power and stowage capacity for supplies, the processing vessel may operate while underway between the mining site and port.

9.5.1 General Physical Requirements

The at-sea processing vessels need both space and weight capacity for each processing plant to accommodate

- Processing plant equipment,
- Nodule storage,
- Reagents and supplies storage,
- Steam generation,
- Power plants for electrical generation,
- Fresh water plants,
- Hotel accommodations for the crew,
- Fuel and equipment,
- Transfer equipment to transportation vessels.

9.5.1.1 Processing Plant Equipment

Any vessel processing plant would need adequate space for the installation of the major equipment items illustrated in Figure 9.5 and for auxiliary facilities such as pumps and piping, and the utility services such as boilers, distillers and power plants. For safety, certain parts of the processing plant should be kept separate from other, less dangerous process units. For simple material handling, the units should be roughly in the same sequence as the process steps and utilize gravity flow whenever practical. Compartmentalization of the vessels and multiple deck levels permit both process unit separation and equipment units to be located in appropriate relationship to each other.

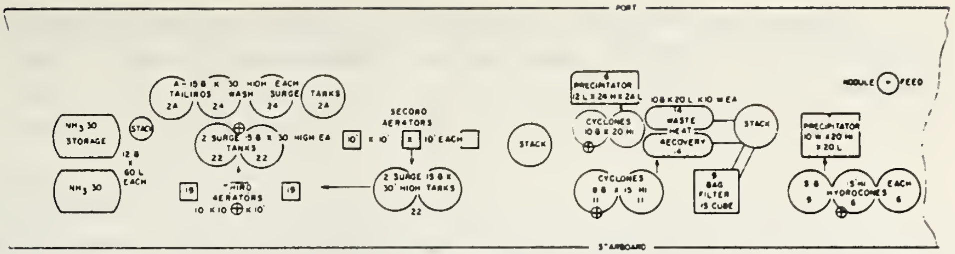
9.5.1.2 Nodule Storage

The process plants would need a buffer stack of nodules on-board to assure continuity of production if the ship should become separated from the stowage or mining ship. The size of this nodule stowage hold would depend upon the mining and processing rates and the estimates of time out of connection. The postulated mining rates are 3400 and 11,400 tonnes (3750 and 12,500 tons) per day. Two day separation may be expected if the mining ship loses its pipeline or because of storms.

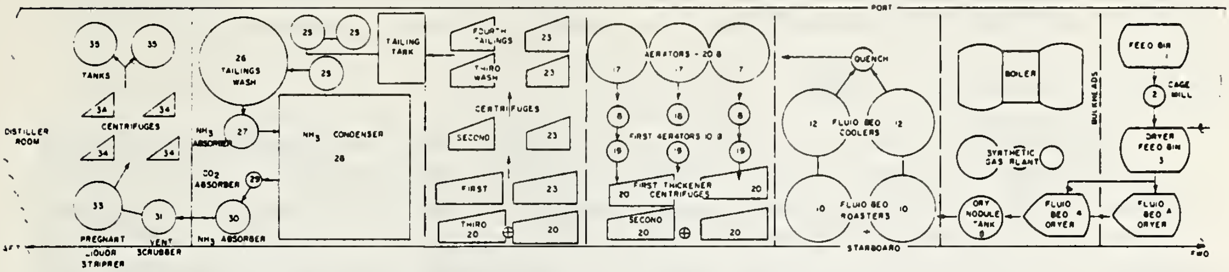
If nodule stowage is on a separate vessel from the process plant, the separation problem because of weather becomes most significant since a train of mining ship, nodule barge, and process ships is even more difficult to control.

9.5.1.3 Reagents and Supplies Storage

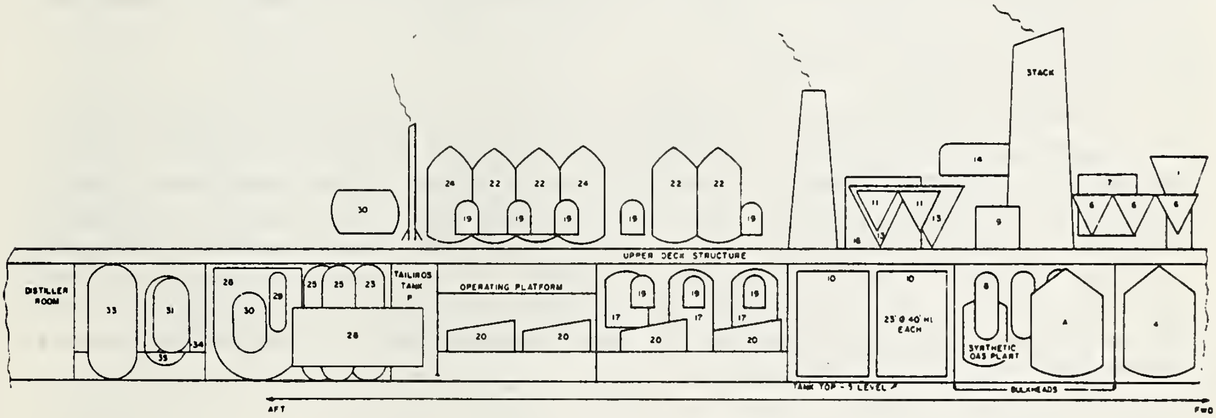
Liquids and solids needed in processing include gaseous fuels in pressure vessels, acids, flocculants, chlorine and ammonia, and large volumes of raffinate from the shore plant for the pregnant liquor productions cases.


PORT
NH3 30 STORAGE
NH3 30
12 Ø x 60 L EACH
STACK
A - 15 Ø x 30 HIGH EACH
TAILINGS WASH SURGE TANKS
24
2 SURGE 15 Ø x 30 HIGH EA TANKS
22
THIRD AERATORS 10 x 10 x 10'
19
SECOND AERATORS
10' x 10'
10' EACH
2 SURGE 15 Ø x 30' HIGH TANKS
22
STACK
PRECIPITATOR 12 L x 24 H x 2A L
CYCLONES 10 Ø x 20 HI
10 Ø x 20 L x 10 H EA
14 WASTE HEAT RECOVERY 14
STACK
CYCLONES 8 Ø x 15 HI
11
9 BAG FILTER 15 CUBE
NODULE FEED
PRECIPITATOR 10 W x 20 HI x 20 L
5 Ø 15' HI HYDROCONES EACH
6
STARBOARD

WEATHER DECK PLAN



HOLD PLAN



ELEVATION - STARBOARD SIDE LOOKING PORT

FIGURE 9.5 LAYOUT OF PLANT EQUIPMENT ON PROCESSING VESSEL

These materials are used in large volumes, and a few are very difficult to handle and stow. Therefore, special facilities are required.

9.5.1.4 Steam

All the at-sea processing plants require substantial flows of saturated steam which are not condensed but are consumed in the process. The process system requirements for saturated steam and electrical power would be met by either installing desuperheaters in marine boilers, or by using the superheated steam to generate electricity in the high-pressure turbine generator stages only.

9.5.1.5 Electrical Power

Electrical power for the process plants must be generated on-board the processing vessel, since cable transfer at sea would be too hazardous. The electrical power requirements of the processes are somewhat in excess of normal maximum boiler output expected in conventional bulk ships. In almost all cases, however, sufficient power for process use can be obtained by letting high pressure superheated steam through backpressure turbines with the exhaust steam used for process heating.

9.5.1.6 Water Requirements

A major addition for a process plant at sea would be installation of a large, sea-water evaporator or distiller to produce both the process and boiler make-up water. Normally, ocean-going ships with normal size crews do not distill water but carry fresh water from shore in tanks because of the relatively high cost of producing fresh water at sea and the low tonnage of water required. However, the volume of water required in all cases is for too large to transport and must be produced at sea. The sizes of the distiller plants are large enough to have efficiencies comparable to shore plants.

9.5.1.7 Hotel Facilities

The hotel installation on board ships includes hot and cold fresh water, sewage, air conditioning, heating and ventilation, and sea water wash services. Standard galley, mess, cleaning, workshop, recreation, and other facilities are ordinarily provided. All of these services would be extended by the operators of the at-sea processing plant. Barges have none of these accommodations. All would be required on a processing vessel.

9.5.1.8 Fuel

Residual fuel oil could be burned in the boilers as fuel for production of power, steam, and fresh water. Large quantities are required and could be carried to the processing vessel either by the transportation ship on each load from shore or on separate tankers from Indonesia or Hawaii. Again, large volumes of fuel bunker space and fast fuel oil transfer systems on the processing vessel would be required.

9.5.1.9 Transfer to Other Vessels

To handle the fuels, and raffinate and reagents from shore and the pregnant liquor to shore, large pumping systems will be needed for the liquids, including transfer-at-sea hoses. For the solids and cake, which move in the lower volumes, container or pallet movement systems would be necessary. However these are cumbersome and dangerous. Many of the solids could be carried by the processing vessel in large enough quantities to last a year and eliminate transfer of solids except for foods. Transfer of the nodules from mining ship to process vessel is also required.

9.5.1.10 Feasibility of Processing Plants on Barges

If processing plants were to be installed on a barge and then towed by tugboat or the mining ship, a propulsion system would not be needed on the processing barge. However, boilers, distillers, generators, condensers, and all the other typical shipboard equipment would still be required on the process barge as well as hotel fittings needed for the process plant crew. The barge would be manned at sea and have the same requirements for safety as a ship. Therefore, little gain would be possible by not installing propulsion and navigation equipment. In fact, because of the plant crew onboard, a standby tugboat may well be required at all times for emergency rescue, as is now common at the North Sea oil platforms.

A barge processing plant could be moored at or near the mine site. In 5000 meters (16,500 feet) of water, this is feasible for small units but is difficult and expensive. For multiple small barges or one large processing and stowage barge, the deep-water mooring would be quite expensive and insecure in bad weather. Also, a mining ship feeding a moored processing barge would need a long connecting floating pipeline and rather frequent respositioning would be required.

For all of these reasons, a self-propelled, single ship processing plant appears to be a much more logical choice than a barge plant or several barges with plant and stowage spread between them.

9.5.2 Shipboard Process Plants

9.5.2.1 Reduction/Ammonia Leach Process

Even when allowance is made for access space, installation room, separation of process segments, and ship subdivision with bulkheads, modest size vessels are adequate for these plants. A ship with 27.4

meters (90-foot) beam and less than 171 meters (560 feet) long, with a hull perhaps 15.2 meters (50 feet) deep, would have adequate space for all the process equipment, ship propulsion and hotel systems, distillers and generators, accommodations for a very large crew, lifesaving equipment, boats, and a helicopter deck. Almost 10,900 tonnes (12,000 tons) of process equipment could be installed on a ship of the size indicated below.

The vessel process plant inputs and outputs are tabulated in Table 9.5 for the pregnant liquor production case and in Table 9.6 for mixed metal precipitate production. The inputs to the at-sea plant, based on 11,400 tonnes (12,500 tons) of nodules per day, total 14,880 tonnes (16,400 tons) of supplies, of which 13 percent is fuel, and 86 percent is raffinate returned from the land plant.

The amount of nodule stowage, pregnant liquor, raffinate and fuel tankage, is a function of the frequency and schedule dependability of transporting ships to shore. If four Panamax ships of 55,000 dwt are used, a vessel would arrive every 2.7 days on the average. With a 24 hour leeway in arrival, a 57,330 tonne (63,000 ton) storage capacity would be required for supplies. The pregnant liquor product to be shipped ashore would have separate tank capacity for 31,850 tonnes (35,000 tons) of liquid. Therefore the total weight of fuel and liquids for 3.7 days, and nodules for one day, is approximately 98,300 tonnes (108,000 tons).

The ship needed for both process plant and stowage would be about the same size as a 130,000 dwt tanker, that is 274 meters (900 feet) length, 42 meters (138 feet) beam and 16.2 meters (53 foot) draft when fully laden at sea. This processing and stowage vessel would resemble a large tanker with some machinery near the center of the ship, on deck and in the holds, and would be a very stable platform.

If larger size transport ships are utilzied and calls made less frequently, even more stowage capacity would be needed. If three transport ships of about 66,000 dwt were used, about 13,650 tonnes (15,000 tons) more stowage capacity would be needed.

If the concept of producing pregnant liquor at sea is used, four transport tankers of 55,000 dwt would be needed. This compares with a need for only two ships of 63,000 dwt for slurry transport of raw nodules.

If the pregnant liquor is stripped at sea to produce a basic metal carbonate cake, the output to the shore plant is reduced substantially, to about 8 percent of the weight of raw nodules, so that significant transportation savings will be possible. In addition, since no raffinate is returned, resupply tonnages decrease to less than 2730 tonnes/day (3000 tons/day) and consist mostly of fuel. Thus, a tanker could refuel the plant every two weeks, or even once a month, depending on process

TABLE 9.5

AT SEA PROCESS PLANT INPUTS AND OUTPUTS FOR PRODUCTION OF PREGNANT LIQUOR

	Reduction/ Ammonia Leach	High Temp. Sulfuric Acid Leach	Cuprion/ Ammonia Leach	Reduction/ Hydrochloric Acid Leach
Process Inputs				
Nodules	11,400; 12,500	11,400; 12,500	11,400; 12,500	3,400; 3,750
Fuels	1,980; 2,180	642; 705	1,230; 1,350	1,370; 1,510
Supplies	13.6; 15	2550; 2800	14.6; 16	1,310; 1,440
Liquids	12,890; 14,170	21,340; 23,450	27,960; 30,730	0
Total Input	14,880; 16,370	24,520; 26,950	29,200; 32,100	2,680; 2,950
Ratio: $\frac{\text{Input Weight}}{\text{Nodule Weight}}$	1.31	2.16	2.57	0.79
Process Outputs (To Shore)				
Pregnant Liquor	7,370; 8,100	21,300; 23,400	20,900; 23,000	4,100; 4,500
Ratio: $\frac{\text{Output Weight}}{\text{Nodule Weight}}$	0.65	1.87	1.84	1.20

Note: All units in this table are tonnes per day; tons per day.

TABLE 9.6

AT SEA PROCESS PLANT INPUTS AND OUTPUTS FOR PRODUCTION OF MIXED METAL PRECIPITATES

	Reduction/ Ammonia Leach	High Temp. Sulfuric Acid Leach	Cuprion/ Ammonia Leach
Process Inputs			
Nodules	11,400; 12,500	11,400; 12,500	11,400; 12,500
Fuels	2,520; 2,770	910; 1,000	2,250; 2,470
Supplies	13.6; 15	3,120; 3,430	14.6; 16
Total Input	2,530; 2,785	4,030; 4,430	2,270; 2,490
Ratio: $\frac{\text{Input Weight}}{\text{Nodule Weight}}$	0.22	0.35	0.20
Process Outputs (To Shore)			
Precipitated Metals	865; 950	755; 830	865; 950
Ratio: $\frac{\text{Output Weight}}{\text{Nodule Weight}}$	0.08	0.07	0.08

Note: All units in this table are tonnes per day; tons per day.

plant ship stowage capacity. A specially equipped general cargo ship could remove the basic metal cake at about the same interval.

The vessel component dedicated to processing would increase to about 20,000 dwt equivalent to hold the additional equipment, but the overall size would decrease since less than 45,500 tonnes (50,000 tons) of fuel, 13,650 tonnes (15,000 tons) of cake and a one day supply of nodules would be on board at any time. Therefore, the process vessel would have a size equivalent to a 100,000 dwt tanker. The transport ships would consist of one 40,000 dwt tanker and one 15,000 dwt cargo ship.

9.5.2.2 High Temperature Sulfuric Acid Process

For pregnant liquor production, this plant is about two-thirds of the size of the ammonia plant of the same throughput capacity, and smaller than the HCl four-metal plant at one-third the capacity. A ship of about 15,000 dwt capacity could carry the plant, but not stowage of associated liquids and solids. Tables 9.5 and 9.6 summarize the at-sea plant inputs and outputs. The total weight of supplies is about 1.9 times the weight of nodules and the weight of pregnant liquors is also about 1.9 times the nodule weight. Four 70,000 dwt tanker ships would be needed to handle the supplies and fuel input and raffinate output, which are about equal in tonnage. Transport ships would call about every 2.5 days.

With a 24-hour cushion and one day supply of nodules, about 173,000 tonnes (190,000 tons) of stowage capacity would be needed. The complete ship would be over 200,000 dwt size. The ship would be over 305 meters (1000 feet) long, 47.6 meters (156 feet) beam, 25.9 meters (85 feet) hull depth and draw 19.8 meters (65 feet).

If the pregnant liquor is treated at sea to produce metal sulfide precipitates, the plant size would be significantly increased and would approach the size required for the ammonia process, approximately 23,000 dwt. The product tonnage decreases to about 7 percent of the raw nodules weight, but a resupply of about 4100 tonnes/day (4500 tons/day) is significant. The major input is sulfuric acid, which requires a moderate degree of containment. Other supplies could be brought out monthly in a 15,000 dwt ship which would also return the sulfides to the shore plant.

A 35,000 dwt tanker calling once a month could carry the required fuel and might also carry the propane/butane required for hydrogen sulfide production. However, capacity for 680 tonnes (750 tons) of LPG is an unusual requirement and pressurized tanks and gas recompression/ refrigeration would be needed. The sulfuric acid would be transported in a chemical carrier, with special tank coatings and handling methods, along with sulfur. A single 15,000 dwt ship calling every two weeks would be adequate for the balance of supply/ product transportation requirements. The processing vessel itself would require stowage capacity for about 95,500 tonnes (105,000 tons) of supplies which, together with the process plant space, dictates a ship of about 130,000 dwt capacity. It would be about 259 meters (850 feet) long, 42 meters (138 feet) beam, and be 22 meters (72 feet) deep.

9.5.2.3 Reduction/Hydrochloric Acid Leach Process

Although only 3400 tonnes/day (3750 tons/day) of nodules are processed in this four-metal plant, the plant equipment requires about three-fourths the space of the reduction/ammonia process. This plant should fit in a ship space two decks high and 122 meters (400 feet) long by 24.4 meters (80 feet) wide. In addition, boiler, distiller, propulsion and generating plant space would be needed. Therefore, a ship of about 155 meters (510 feet) x 24 meters (80 feet) beam, or 17,000 dwt, could accommodate the plant, but have no stowage space.

Table 9.5 summarizes the at-sea plant inputs and outputs. This process does not require recycling of raffinate or liquor from shore, but does consume relatively more supplies at sea. This includes transportation and handling of large amounts of liquid chlorine. The output to shore in pregnant liquor is about 20 percent higher than the weight of nodules mined.

Because of the lower tonnage involved, one tanker of about 70,000 dwt would be adequate for chlorine, fuel oil, and pregnant liquor movement to and from Southern California ports. However, almost 13 days between ship calls would require about two weeks stowage capacity, or 34,600 tonnes (38,000 tons) of supplies and 52,800 tonnes (58,000 tons) of product, plus one day supply of nodules. Therefore the stowage capacity required, approximately 87,400 tonnes (96,000 tons), is the same range as for the ammonia process ship. Thus, the smaller four-metal process plant makes little difference in the overall stowage and process plant vessel size, unless a larger fleet of smaller transport ships were used.

The carriage of chlorine at sea is most hazardous and requires a Class I type ship with separate cargo tanks, not only for the chlorine but all other chemicals onboard. At present the United States Coast Guard will not certify a manned vessel to carry chlorine in bulk quantities. However, about 1140 tonnes/day (1250 tons per day) are required by the HCl process plant, too much for barrel handling, and too little for efficient ship loads. If the chlorine cannot be carried in independent deck tanks on the tanker, then a barge load could be pulled. Presumably the process ship would be allowed to pump chlorine into holding tanks.

Carriage of both LPG and chlorine at the same time is not likely, although the same cryogenic cargo tanks and pumping system could be utilized. Therefore, the use of two transport tank ships is anticipated, one for LPG and the other for chlorine, and both carry fuel and flocculants.

9.5.2.4 Cuprion/Ammonia Leach Process

This plant is about as large as the ammonia reduction plant of the same throughput, and has many of the same components and processes. However, the process inputs and outputs are much larger for the pregnant liquor production case, as shown in Table 9.5. Inputs and outputs for BMC production are summarized in Table 9.6. Although the fuel oil required is less, the addition of returned raffinate and reduction liquors increased the daily outbound load from shore to process ship. Even the inbound load to shore is almost twice the mineral weight of manganese nodules. One large transport ship would call every other day, and six 70,000 dwt ships would be needed to transport the pregnant liquor ashore. Almost 9.1 million tonnes (10 million tons) would be moved outbound annually. Again, the necessary stowage capacity and the process plant together would require a large ship well over 215,000 dwt, which is comparable to the sulfuric acid process ship in size.

As is the case with the reduction/ammoniacal leach process, pregnant liquor stripping for BMC production greatly decreases transportation requirements. With about 2300 tonnes/day (2500 tons/day) resupply required, a small tanker calling once or twice a month would be adequate, depending on process ship stowage capacity. The same rate of call would be required for removal of BMC cake, but a separate ship would be needed.

The process space required for BMC production would be less than that provided by a 20,000 dwt ship. Provision for stowage of fuel, supplies, and nodules, however, would result in a ship with a capacity of about 100,000 dwt being used.

9.5.3 Summary and Possible Alternatives to Selected Process Vessels

9.5.3.1 Summary

In all four processes for the production of pregnant liquor, a large volume of liquid would be moved inbound to shore. The largest item moved out to sea is raffinate, except for the HCl process. In addition, the fuel oil transport tonnage alone would be substantial. However, this could be performed separately by tankers from Indonesia or Hawaii rather than loaded out from the United States. Finally, supplies, in some cases hazardous liquids, and a small cargo of dry chemicals would have to be transported. Therefore, tankers would be the most appropriate type of transport ships.

In aggregate, the processes require enormous throughputs, summarized in Table 9.7, on a weekly basis to maintain an 11,400 tonnes per day (12,500 tons per day) nodule mining rate.

TABLE 9.7

WEEKLY TONNAGE FOR AT-SEA PROCESSING PREGNANT LIQUOR PRODUCTION

	Ammonia	Sulfuric Acid	Hydrochloric Acid	Cuprion
Outbound	104; 115	172; 189	19; 21	204; 225
Inbound	52; 57	149; 164	29; 32	146; 161
Total	156; 172	321; 353	48; 53	350; 386

Note: Units are tonnes/week; tons/week.

The number of tanker ships to transport reagents and supplies ranges from one to six ships of very large size for the shortest haul. For longer hauls, a 50 percent to 200 percent increase in ships would be needed. Increases in costs would be of comparable magnitude.

This large number of tankers would call frequently at the processing ship, with about every other day arrivals or every third day under ideal circumstances for the largest ship. The mining ship would probably begin receiving fuel and liquid supplies and raffinate or liquor for many hours of pumping operation before beginning to pump pregnant liquor to the transport tank ship. To allow for schedule uncertainties and maintain processing of nodules, a generous tankage of at least one-half week's operation would be desired at the ocean processing site. Therefore, the total tonnage listed on Table 9.7 would be double the necessary capacity of the processing ship. This is cargo and is in addition to in-process fluids and the process equipment weight.

Therefore, the ship size needed for the process plant is moderate, as shown by the ammonia plant example. However, the ship size required for liquids stowage when producing pregnant liquor is quite large, between 90,000 and 215,000 dwt. Consequently, an integrated process plant and liquid stowage vessel would be enormous, about 305 meters (1000 feet) in length, 46 meters (150-foot) beam, and 15.2 meters (50-foot) draft when normally loaded at sea.

The production of metal precipitates at sea eliminates the movement of pregnant liquor and the raffinate return which generated most of the transportation requirement. Thus the need for large stowage capacity to discharge and load the transport ships quickly is not required. (This method of precipitation does not apply to the four-metal HCl process at sea.) The process vessel stowage ranges from 35 percent to 100 percent less than with the liquids for transport. Also, the transport vessel requirement is reduced for the three suitable processes--ammonia, sulfuric acid and cuprion.

Table 9.8 compares the vessel requirements for all alternatives of partial at-sea processing and transportation. For the pregnant liquor production, the HCl process appears to have advantages. For metal cake production, the reduction/ammonia and cuprion process are almost equal in vessel requirements, and even comparable to the HCl (four-metal) at-sea plant. All three processes utilize a general cargo ship to move the metal cake to shore, which is less than 910 tonnes (1000 tons) per day. All three processes need fuel carried by a tanker at frequent intervals to reduce oil bunker space requirements. In addition, the sulfuric acid process needs a chemical tanker to carry the needed volume of sulfuric acid.

TABLE 9.8

SUMMARY OF AT-SEA PROCESS VESSEL AND TRANSPORTATION SHIPS

Pregnant Liquor Production

Vessel Descriptions	Reduction/ Ammoniacal Leach	Reduction/ Reduction/ Hydrochloric Acid Leach	High Temperature Sulfuric Acid Leach	Cuprion/ Ammoniacal Leach
Process Plant, (DWT)	130,000	90,000	205,000	215,000
No. of Transport Ships(4)	4(1)	2(1)	4(1)	6(1)
Size, (DWT)	55,000	43,000	70,000	70,000
Production of Metal Precipitates				
Process Plant (DWT)	100,000	N/A	130,000	100,000
No. of Transport Ships(4)	2(2)	N/A	3(3)	2(2)
Size, (DWT)	40,000		40,000	35,000
	15,000		35,000 + LPG	15,000
			15,000	

---

(1) Tankers.

(2) Tanker plus general cargo ship.

(3) Two tankers plus general cargo ship.

(4) These vessels would be required in lieu of ore-type nodule transport ships.

The worst hazards in sea transportation are generated by the large volumes of chlorine, ammonia, propane and butane (LPG) and sulfuric acid, in that order. The HCl processes needs large quantities of LPG and chlorine. The high temperature sulfuric acid process also uses sulfur, LPG in small amounts, lime and limestone. On balance, an at-sea process based on ammonia leaching appears to present the lowest transportation safety problem.

Partial at-sea processing of manganese nodules is technically feasible, but may become economically feasible only if land processing plants face formidable obstacles for operation and disposal of wastes. Full processing at sea of manganese nodules to metals would doubtless have severe technical difficulties. The desire to reduce the volume of material transported to shore is difficult to achieve with partial processing. Substantial increases in transport weight of semi-processed nodules and process supplies may about double the transport ship investment and operating cost. However, the importance of these costs must be measured relative to the cost of the shore-based operation, which are not yet defined.

9.5.3.2 Process Alternatives

The at-sea processing options for the production of pregnant liquor are dominated by the problems in handling pregnant liquor and raffinate. Reduction in these volumes by a factor of two would have enormously favorable consequences. For this to occur, however, the centrifuges which were substituted for thickeners would have to function more efficiently than has been assumed. If higher slurry densities were attained, less wash water would need to be introduced into the leaching circuit and more concentrated pregnant liquors might be obtained. Thus, demonstrations of acceptable centrifuge performance would likely be a precondition to development of at-sea processing technology. In addition, an increase in pulp density would decrease water losses which occur when washed tailings are dumped at sea. Since the fuel required for distilling fresh water amounts to 40 percent of the total required in some cases, the savings could be significant. Some desalinization will always be required for boiler water make-up and other uses, but if sea water could be used directly without excessive corrosion problems being introduced, there would be significant incentive to do so.

Another alternative addressed was the division of the beneficiation and several processing steps into discrete sections to be accomplished on several vessels at sea. The partial at-sea processing plants were derived from examination of the integrated plant designed for land operation. Proper plant design calls for use of heat from exothermic reactions and waste heat from wherever available in processes to be used where needed. When plant splitting is begun, these energy-saving possibilities are sometimes eliminated. Also, the need for certain reclaiming or cleaning operations at many places in the process, such as ammonia recovery, requires two such plants when the integrated process is split.

The at-sea process plants could be split more, and installed on more than one vessel with penalties as described above. But the principal problem of the amount of materials used at sea and transported would be aggravated rather than reduced. In case of delays of movement of liquids from one vessel plant to the next, buffer storage would be needed on the supplied ship to maintain processing, as well as dump storage on the supplying ship to maintain its processing. Since this is already a major difficulty, further split of the plant is not likely.

9.5.3.3 Vessel Alternatives

The offshore processing plant may be constructed on a new hull or installed on an existing vessel. A substantial number of large barges are in service under American flag. Although a detailed inventory, such as available from the Coast Guard or Customs, has not been analyzed, many large barges adequate in size for installation of a processing plant may be available. However, as noted above, the use of barges is considered unlikely for at-sea processing.

9.6 CHARACTERIZATION OF LAND-BASED PROCESSING PLANTS FOR AT-SEA PREPROCESSING

9.6.1 Reduction/Ammoniacal Leach Process

The separation between at-sea and land-based processing for the Reduction/Ammoniacal Leach Process is shown in Figure 9.1. The configuration of the land-based plant for pregnant liquor processing is essentially identical to that described in the base case (full processing on land); except that the front-end, consisting of nodules receiving, ore preparation and drying, reduction, leaching, and washing, as well as producer gas generation, is not included. In addition, the tailings stripping operation is removed from the ammonia recovery section. The land-based plant then consists of the liquid ion exchange extraction and stripping sections, copper and nickel electrowinning, cobalt recovery, ammonia recovery, and materials handling and services sections.

If a mixed basic metal carbonate (BMC) is produced at sea and processed in a land plant, additional processing steps are required for BMC dissolution and carbonate removal. The former is carried out by dissolving the wet BMC cake in recycled raffinate while the carbonate is removed by reactions with lime.

The plant inputs and outputs are summarized in Table 9.9. The requirement for raw materials, particularly coal, is greatly reduced because reduction and the tailing stripping occur at sea. Purchased power, however, is not greatly reduced because the electrowinning operations still occur on land. The raw nodules input is replaced either by a large flow of pregnant liquor (and an additional output, raffinate, is produced which must be returned to the at-sea pre-processing plant) or by a small flow of BMC (with nothing returned to sea). The amount of

TABLE 9.9

LAND PLANT INPUTS AND OUTPUTS
REDUCTION/AMMONIA LEACH PROCESS

Major Inputs	Pregnant Liquor Production		BMC Production	
Pregnant Liquor/BMC Cake	2.43×10^6 m^3/yr;	642×10^6 gpy	285×10^3 mtpy;	313×10^3 tpy
Coal	48.7×10^3 mtpy;	53.5×10^3 tpy	48.7×10^3 mtpy;	53.5×10^3 tpy
Limestone	1.46×10^3 tpy;	1.6×10^3 tpy	1.46×10^3 tpy;	1.6×10^3 tpy
Lime	8.5×10^3 tpy;	9.3×10^3 tpy	45.2×10^3 mtpy;	49.7×10^3 tpy
Water	2.7×10^6 m^3/yr;	713×10^6 gpy	0.72×10^6 m^3/yr;	190×10^6 gpy
Gases	8.5×10^3 mtpy;	9.3×10^3 tpy	8.5×10^3 mtpy;	9.3×10^3 tpy
Liquids	4.72×10^3 m^3/yr;	$1,245 \times 10^3$ gpy	4.72×10^3 m^3/yr;	$1,245 \times 10^3$ gpy
Solids	1,940 mtpy;	2,130 tpy	1,940 mtpy;	2,130 tpy
Purchased Power	183×10^6 kwh		188.5×10^6 kwh	
Major Outputs				
Return Raffinate Liquid	4.25×10^6 m^3/yr;	$1,121 \times 10^6$ gpy	0	
Solid Wastes	26.1 mtpy;	28.7×10^3 tpy	92×10^3 tpy;	101×10^3 tpy
Liquid Wastes	0.12×10^3 m^3/yr;	32.3×10^3 gpy	0.19×10^3 m^3/yr;	49.6×10^3 gpy
Stacked Off-Gases	1.9×10^3 m^3/min;	67×10^3 scfm	1.9×10^3 m^3/min;	67×10^3 scfm
Low Level Emissions	2.1×10^3 m^3/min;	75×10^3 scfm	2.2×10^3 m^3/min;	77×10^3 scfm
Copper	$2\ 7.7 \times 10^3$ mtpy;	30.4×10^3 tpy	27.7×10^3 mtpy;	30.4×10^3 tpy
Nickel	33.0×10^3 mtpy;	36.3×10^3 tpy	33.0×10^3 mtpy;	36.3×10^3 tpy
Cobalt	3.9×10^3 mtpy;	4.3×10^3 tpy	3.9×10^3 mtpy;	4.3×10^3 tpy

tailings and wastes produced is greatly reduced, consisting in this case mainly of solids from the lime boil operations.

The requirement for support services, particularly transportation, will be reduced in proportion to the input of production supplies. The elimination of the front-end operations will reduce the labor requirements somewhat. It is estimated that about 400-450 people will be employed in the land-plant. In addition, elimination of the leach and tailings wash thickeners and the requirement for a large raw nodules storage area would decrease the plant area requirement to approximately 61 hectares (150 acres).

9.6.2 High Temperature Sulfuric Acid Leach Process

The separation of at-sea and land-base processing operations for the high temperature sulfuric acid leach process is shown in Figure 9.2. The configuration of the land-based plant for processing pregnant liquor is identical to that of the base case, with the exception that nodules receiving, ore preparation, leaching, and nodules washing are carried out at sea. The land-based plant consists of pH adjustment and raffinate neutralization steps, copper and nickel liquid ion exchange extraction, stripping, and electrowinning steps, cobalt recovery, ammonia recovery, and materials handling and services operations.

If a mixed metal sulfide precipitate is produced at sea for processing in a land-based plant, an additional step, sulfide dissolution, is required. This is accomplished by oxygen pressure leaching in a manner similar to that used in the smelting process. All other process steps are the same as for pregnant liquor processing, except that the materials requirement for the pH adjustment and neutralization steps are reduced because the leach solution is more concentrated in metals and largely free of other impurities.

Plant inputs and outputs are summarized in Table 9.10. While the steam requirements for leaching are eliminated, those for ammonia recovery remain the same and a significant amount of coal is still required. The purchased power requirements remain high since the electrowinning power demands are only partially offset by internal power generation. The consumption of sulfuric acid is greatly reduced, since leaching takes place at sea, and raw nodules input is replaced by a large flow of pregnant liquor. While process solid wastes are decreased considerably since tailings are disposed of at sea, the lime-boil operation still produces a significant amount of gypsum which, in this case, constitutes approximately 90 to 95 percent of the total wastes discharged.

The requirement for support services is also diminished because of the decreased flow of raw materials, and elimination of the front-end operations would reduce labor requirements to approximately 400-450 people. Elimination of tailings washing thickeners and raw nodules

TABLE 9.10

LAND PLANT INPUTS AND OUTPUTS
HIGH TEMPERATURE SULFURIC ACID LEACH PROCESS

Major Inputs	Pregnant Liquor Production	Mixed Metal Sulfide Production
Pregnant Liquor/BMC Cake	6.39×10^6 m^3/yr; 1,687 $\times 10^6$ gpy	249 $\times 10^3$ mtpy; 274 $\times 10^3$ tpy
Coal	190 $\times 10^3$ mtpy; 209 $\times 10^3$ tpy	54.6×10^3 mtpy; 60 $\times 10^3$ tpy
Limestone	87 $\times 10^3$ tpy; 96 $\times 10^3$ tpy	54.6×10^3 mtpy; 60 $\times 10^3$ tpy
Lime	318 $\times 10^3$ tpy; 350 $\times 10^3$ tpy	87 $\times 10^3$ mtpy; 96 $\times 10^3$ tpy
Water	2.96×10^6 m^3/yr; 782 $\times 10^6$ gpy	1.89×10^6 m^3/yr; 499 $\times 10^6$ gpy
Gases	9.5×10^3 mtpy; 10.4×10^3 tpy	60.4 mtpy; 995 tpy
Liquids	3.26×10^3 m^3/yr; 861 $\times 10^3$ gpy	4.21×10^3 m^3/yr; 1,112 $\times 10^3$ gpy
Solids	3,450 mtpy; 3,792 tpy	905 mtpy; 995 tpy
Sulfuric Acid	57 $\times 10^3$ mtpy; 63 $\times 10^3$ tpy	364 $\times 10^3$ mtpy; 400 $\times 10^3$ tpy
Purchased Power	115.6 $\times 10^6$ kwh	189 $\times 10^6$ kwh
Major Outputs		
Return Raffinate Liquid	3.13×10^6 m^3/yr; 826 $\times 10^6$ gpy	0
Solid Wastes	652 $\times 10^3$ mtpy; 716 $\times 10^3$ tpy	228 $\times 10^3$ mtpy; 250 $\times 10^3$ tpy
Liquid Wastes	0.89×10^3 m^3/yr; 236 $\times 10^3$ gpy	0.3×10^3 m^3/yr; 100 $\times 10^3$ gpy
Stacked Off-Gases	4.3×10^3 m^3/min; 150 $\times 10^3$ scfm	1.2×10^3 m^3/min; 41 $\times 10^3$ scfm
Low Level Emissions	5.2×10^3 m^3/min; 182 $\times 10^3$ scfm	3.2×10^3 m^3/min; 112 $\times 10^3$ scfm
Copper	29.1×10^3 mtpy; 32 $\times 10^3$ tpy	29.1×10^3 mtpy; 32 $\times 10^3$ tpy
Nickel	34.8×10^3 mtpy; 38.2×10^3 tpy	34.8×10^3 mtpy; 38.2×10^3 tpy
Cobalt	3.7×10^3 mtpy; 4.1×10^3 tpy	3.7×10^3 mtpy; 4.1×10^3 tpy

storage areas would reduce plant land requirements to approximately 53 hectares (130 acres).

9.6.3 Reduction/Hydrochloric Acid Leach Process

The separation between at-sea preprocessing and land-based operations for the reduction/hydrochloric acid leach process is shown in Figure 9.3. The process configuration is essentially the same as for the base case, except that nodules receiving, preparation, and drying, hydrochlorination and hydrolysis and leaching and washing are carried out at sea. Hydrogen chloride and chlorine recovery are carried out both at sea and on land and a chlorine burning (hydrogen chloride production) step is added to the at-sea processing scheme. Copper and nickel ion exchange extraction and stripping and electrowinning are carried out in the land plant as are cobalt extraction and stripping and cobalt recovery, chloride salt drying and fused salt electrolysis for manganese recovery and the provision of process materials handling and services for the land-based operations. The chlorine recovered in the land-based plant is compressed and liquified for return to the at-sea preprocessing plant. Elimination of the requirement for large volumes of hydrogen chloride for use in the land-based plant eliminates the need to tie this facility to an adjacent caustic-chlorine/chlorinated hydrocarbon production facility. However, the requirements of the at-sea plant are such that an additional 364 tonnes (400 tons)/day of chlorine would have to be purchased from external sources to supplement the chlorine recovered from the land-based operations.

Plant inputs and outputs are summarized in Table 9.11. While the requirement to trade chlorine and hydrogen chloride over-the-fence is eliminated, purchased power needs remain high to support the electrolytic reduction of manganese. Coal consumption is reduced significantly since the large steam demand associated with hydrogen chloride recovery has been eliminated. While at-sea disposal of leach tailings reduces this component of solid waste significantly, the amount of fused salts to be disposed of remains the same since they are produced during the manganese reduction step.

9.6.4 Cuprion/Ammonia Leach Process

The separation of at-sea and land-based processing operations for the Cuprion/Ammonia Leach Process is shown in Figure 9.4. The configuration of the land plant is the same as for base case conditions when pregnant liquor is processed except that nodules receiving, ore preparation, reduction, leaching and washing, producer gas generation and tailings stripping occur at sea. Liquid ion exchange extraction and stripping, copper and nickel electrowinning, cobalt recovery and the raffinate stripping operations in ammonia recovery are retained in the land plant as are the materials handling and services sections.

TABLE 9.11

LAND PLANT INPUTS AND OUTPUTS
REDUCTION/HYDROCHLORIC ACID LEACH PROCESS

Major Inputs	Pregnant Liquor Production	
Pregnant Liquor	0.97 x 10^6 m^3/yr;	256 x 10^6 gpy
Coal	59 x 10^3 mtpy;	65 x 10^3 tpy
Limestone	2.7 x 10^3 tpy;	3 x 10^3 tpy
Lime	3.8 x 10^3 tpy;	4.2 x 10^3 tpy
Water	0.72 x 10^6 m^3/yr;	190 x 10^6 gpy
50% Caustic Solution	27.0 x 10^3 tpy;	29.7 x 10^3 tpy
Gases	218 x 10^3 mtpy;	239 x 10^3 tpy
Liquids	3.79 x 10^3 m^3/yr;	1,000 x 10^3 gpy
Solids	888 mtpy;	976 tpy
Purchased Power	864 x 10^6 kWh	
Major Outputs		
Fused Salts	212 x 10^3 mtpy;	233 x 10^3 tpy
Chlorine	376 x 10^3 mtpy;	413 x 10^3 tpy
Solid Wastes	15.9 x 10^3 mtpy;	17.5 x 10^3 tpy
Liquid Wastes	0.06 x 10^3 m^3/yr;	16.6 x 10^3 gpy
Stacked Off-Gases	2.3 x 10^3 m^3/min;	80 x 10^3 scfm
Low Level Emissions	2.5 x 10^3 m^3/min;	90 x 10^3 scfm
Copper	8.7 x 10^3 mtpy;	9.6 x 10^3 tpy
Nickel	11.1 x 10^3 mtpy;	12.2 x 10^3 tpy
Cobalt	1.7 x 10^3 mtpy;	1.9 x 10^3 tpy
Manganese	188 x 10^3 mtpy;	207 x 10^3 tpy

The requirement for plant support components would also decrease somewhat, with personnel levels dropping to 250 people because of the elimination of the front-end operations. Elimination of tailings washing and raw nodules storage areas would decrease total land requirements to approximately 30 hectares (75 acres), and the transportation network to support plant activities would decrease in proportion to the requirements for raw materials.

When processing a BMC produced at sea, however, the additional steps of cake dissolution and carbonate removal are required in the land plant. Also, since no liquors are returned to sea, the raffinate stripping operation is eliminated from the land plant as well, which greatly reduces steam generation and other service requirements.

Plant inputs and outputs are summarized in Table 9.12. The reduction in coal requirements is not as great as for the Reduction/Ammonia Leach Process when processing pregnant liquor, because the raffinate stripping step remains in the land-based plant. However, the additional power generated from steam raised for this step gives a proportionately greater decrease in purchased power requirements for this case. As is the case for the Reduction/Ammonia Leach Process, the amount of process waste is significantly reduced since tailings are disposed of at sea, leaving mainly lime-boil solids and combustion ash to be disposed of on land. The raw nodules input is eliminated, being replaced by pregnant liquor, and a corresponding amount of raffinate is produced for return to the sea-based operation.

Since raffinate stripping is performed at sea when processing BMC, the steam and coal requirements are reduced by amounts comparable to the Reduction/Ammonia Leach case, and a large flow of pregnant liquor is replaced by a small amount of BMC cake. Return of raffinate is eliminated.

The requirements for support services are also reduced, as is the case for the other process options examined. Transportation requirements are decreased in proportion to the input of raw materials, manning levels decrease to approximately 400-450 people because of the elimination of front-end processing requirements. Plant area requirements decrease to 61 hectares (150 acres) because of the elimination of leaching and tailings washing thickeners and raw nodules storage ponds.

TABLE 9.12

LAND PLANT INPUTS AND OUTPUTS
CUPRION/AMMONIA LEACH PROCESS

Major Inputs	Pregnant Liquor Production	BMC Production
Pregnant Liquor/BMC Cake	6.89 x 10^6 m^3/yr; 1,820 x 10^6 gpy	286 x 10^3 mtpy; 314 x 10^3 tpy
Coal	328 x 10^3 mtpy; 360 x 10^3 tpy	58 x 10^3 mtpy; 64 x 10^3 tpy
Limestone	11.4 x 10^3 tpy; 12.5 x 10^3 tpy	2.3 x 10^3 mtpy; 2.5x 10^3 tpy
Lime	8.5 x 10^3 tpy; 9.3 x 10^3 tpy	45.2 x 10^3 mtpy; 49.7 x 10^3 tpy
Water	3.60 x 10^6 m^3/yr; 950 x 10^6 gpy	0.72 x 10^6 m^3/yr; 190 x 10^6 gpy
Gases	7.7 x 10^3 mtpy; 8.5 x 10^3 tpy	7.7 x 10^3 mtpy; 8.5 x 10^3 tpy
Liquids	4.83 x 10^3 m^3/yr; 1,275 x 10^3 gpy	4.83 x 10^3 m^3/yr; 1,275 x 10^3 gpy
Solids	6,490 x 10^3 mtpy; 7,140 x 10^3 tpy	6,490 x 10^3 mtpy; 7,140 x 10^3 tpy
Purchased Power	0	183 x 10^6 kwh
Major Outputs		
Return Raffinate Liquid	7.42 x 10^6 m^3/yr; 1,958 x 10^6 gpy	0
Solid Wastes	114 x 10^3 mtpy; 125 x 10^3 tpy	139 x 10^3 mtpy; 153 x 10^3 tpy
Liquid Wastes	0.47 x 10^3 m^3/yr; 125 x 10^6 gpy	0.52 x 10^3 m^3/yr; 138 x 10^3 gpy
Stacked Off-Gases	7.1 x 10^3 m^3/min; 250 x 10^3 scfm	1.3 x 10^3 m^3/min; 45 x 10^3 scfm
Low Level Emissions	6.1 x 10^3 m^3/min; 215 x 10^3 scfm	2.4 x 10^3 m^3/min; 84 x 10^3 scfm
Copper	27.7 x 10^3 mtpy; 30.4 x 10^3 tpy	27.7 x 10^3 mtpy; 30.4 x 10^3 tpy
Nickel	32.4 x 10^3 mtpy; 35.6 x 10^3 tpy	32.4 x 10^3 mtpy; 35.6 x 10^3 tpy
Cobalt	3.9 x 10^3 mtpy; 4.3 x 10^3 tpy	3.9 x 10^3 mtpy; 4.3 x 10^3 tpy

10.0 GLOSSARY

Agglomeration - In ore beneficiation, a concentration process based on the adhesion of pulp particles. Loosely bonded associations of particles and bubbles are formed which are heavier than water; gravity is used to separate the agglomerates from non-agglomerated particles.

Ammoniacal - Of, relating to, containing, or having the properties of ammonia.

Anion - A negatively charged ion, such as a hydroxide, a chloride, or a sulfate ion; opposite of cation. The ion in an electrolyzed solution that migrates to the anode where it is discharged and liberated or deposited.

Anode - The electropositive pole. The electrode at which electrons leave a device to enter the external circuit; opposite of cathode.

Aqueous - Of, relating to, or having the characteristics of water; watery.

Autoclave - A closed vessel for conducting chemical reactions under high pressure. To treat in such a vessel.

Briquetting - To form loose, powdery substances into a compact form (briquette), usually by compression with or without the use of heat or other agents.

Calcine - To expel volatile matter by heat, as carbon dioxide, water, or sulfur, with or without oxidation; to roast; to burn.

Carbonation - The process of introducing carbon dioxide into a solid or fluid.

Cathode - The electrode where electrons enter (current leaves) an operating system, opposite of anode. In a battery or electrolytic cell, it is the electrode where reduction occurs. The product formed by deposition of metal by electrolytic reduction.

Cation - The element or the positive ion which appears at the cathode or negative terminal in an electrolytic cell. An ion having a positive charge, such as cupric, sodium, or hydrogen.

Cementation - The removal of an ion in solution by reduction with another metal lower in the electromotive series, as the reduction of cupric ion from solution with simultaneous dissolution of metallic iron. Also called precipitation.

Centrifuge - A rotating device for separating liquids of different specific gravities or for separating suspended particles, such as clay particles in an aqueous suspension, according to particle-size fractions, by centrifugal force.

Chelating Agent - A substance which contains two or more electron donor groups and which will combined with a metal ion so that one or more rings are formed. In metal finishing, a chelating agent is used to control or eliminate certain metallic ions present in undesirable quantities. In extractive metallurgy it is used to remove selectively one ion from a mixture in solution.

Clarifier - A centrifuge, setting tank, or other device for separating suspended solid matter from a liquid to produce an essentially solid free liquid stream and a more concentrated solids stream.

Classifier (air, rake) - The term classifier is used in particular where an upward current of air is used to remove fine particles from coarser material. The rake classifier is a device that takes ball-mill discharge and separates it into two portions by mechanical means.

Coextract - To withdraw together, not necessarily in equal portions, substances (as dissolved metals) by physical or chemical process; also, to treat with a solvent so as to remove soluble substances.

Condenser-Absorber - An apparatus for removing heat from a gas (steam) so as to cause the gas to revert to the liquid state to be absorbed by more liquid such as water.

Countercurrent Decantation (CCD) - The clarification of wash water and the concentration of tailings by the use of several thickeners in series. The water flows in the opposite direction from the solids. The final products are slurry which is removed as fluid mud and clear water which is reused in the circuit or, containing valuable constituents, is sent to further processing.

Cyclone - Refers to the conical-shaped apparatus used in dust collecting operations and fine grinding applications. In principle, the cyclone varies the speed of a fluid which determines whether a given particle will be removed through force of gravity or be carried through friction.

Demisting - The removal of liquid droplets suspended in a gas.

Densification - To increase the density or concentrations of a substance.

Dissolution - The act or process of dissolving or breaking up; as a separation into component parts, usually into an aqueous solution.

Electrolyte - A nonmetallic electric conductor (as a solution, liquid, or fused solid) in which current is carried by the movement of ions instead of electrons with the liberation of matter at the electrodes.

Electrolytic - Of or relating to electrolysis or an electrolyte; produced by electrolysis.

Electrostatic Precipitator (ESP) - A device for removing dust particles from air or gases. A high voltage is maintained between a grid of elements through which the dust laden gas passes. Ionization of the gas permits charged dust particles to migrate to collection points and be removed.

Electrowinning - Reductions of metal from a solution by means of electrochemical processes. When sufficient voltage is applied, metallic ions in solution are reduced and deposited at the cathode.

Endothermic - Accompanied by the absorption of heat, opposite of exothermic.

Evaporator/Crystallizer - A specially designed apparatus that crystallizes materials in solution. Supersaturation is produced by evaporation, usually without appreciable cooling.

Exothermic - Characterized by or formed with the evolution of heat, opposite of endothermic.

Fayalite - A silicate of iron, Fe_2SiO_4, belong to the chrysolite group; orthorhombic.

Flocculant - An agent that induces or promotes flocculation, or produces floccules or other aggregate formation.

Flotation - The method of mineral separation in which a froth created in water by a variety of reagents floats some finely crushed minerals (typically surface active sulfides) whereas other minerals sink. If the particles are retained in a foamy layer several inches thick, the process is called froth flotation. Air flotation is carried out in a vessel agitated by air dissolved or blown in.

Fluxing - Fusion or melting of a substance as a result of chemical action which causes the development of the liquid phase by the admixture of low melting components.

Fugitives - Light particles of material treated in roasters, smelting furnaces, and converters that are inadvertently carried out of the unit suspended in the off-gas.

Fused Salts - Salts, that is, ionic compounds, in the molten state. High temperatures are usually involved in maintaining the molten state. Sodium chloride is the principle ingredient in many fused salts.

Gangue - Undesired minerals associated with ore, mostly nonmetallic. The nonmetalliferous or nonvaluable metalliferous minerals in the ore.

Gypsum - A hydrated calcium sulfate, $CaSO_4.2H_2O$.

Hydrochlorination - The process of treating a material with hydrochloric acid to produce a physical or chemical change or both.

Hydrocyclone - A cyclone separator in which water is used.

Hydrolysis - A chemical reaction involving alterations of a substance with the addition of the elements of water.

Hydrometallurgical - Pertaining to hydrometallurgy, the treatment of ores, concentrates, and other metal-bearing materials by wet processes, usually involving the solution of some component, and its subsequent recovery from the solution.

Ion Exchange - The exchange of ions contained in a solid for different ions in solution without destruction of crystal structure or disturbance of electrical neutrality. The process is accomplished by diffusion and occurs typically in solids possessing one or two dimensional channel ways where ions are relatively weakly bonded. Ions may also be exchanged between two liquid phases, as an aqueous and immiscible organic phase.

Laterite - Red residual soil developed in humid, tropical, and subtropical regions of good drainage. It is leached of silica and contains concentrations particularly of iron oxides and hydroxides and aluminum hydroxides, and is an important source of nickel.

Leaching - Extracting a soluble metallic compound from an ore by selectively dissolving it in a suitable solvent, such as water, sulfuric acid, hydrochloric acid, etc. The solvent is usually recovered by precipitation of the metal or by other methods.

Lime Boil - A chemical reaction between lime and ammonium sulfate where steam is introduced to the reacting slurry. Ammonia is released and gypsum is formed.

Liquor - A liquid substance, usually an aqueous solution containing dissolved metals or salts.

Lixiviant - A reagent to extract a soluble constituent from a solid mixture by washing or leaching.

Matte - A metallic sulfide mixture made by melting the roasted product in smelting sulfide ores of copper, lead, nickel, and zinc.

Mill - In mineral processing, one machine, or a group, used in crushing and grinding - comminution - of ore.

Mixer-Settler - A combination of a mixing and settling apparatus into a single unit or stage and the combining of a number of stages to create a process that allows for interaction by mixing and separation by settling to produce a more complete or thorough reaction between aqueous solutions and organic liquids.

Organic - Being, containing, or relating to carbon compounds, especially in which hydrogen is attached to carbon whether derived from living organisms or not.

Overflow-Entrainment - The particles remaining in a solution that is taken from the top of a settled solution.

Oxidation - Combination with oxygen; increase the oxygen content of a compound; increase in valancy of electropositive part of compound, or decrease in valancy of electronegative part. A reaction in which there is an increase in valance resulting from a loss of electrons.

Precipitate - To separate a solid form from a solution by chemical means.

Pregnant Liquor - A value-bearing solution in a hydrometallurgical operation.

Process - A series of chemical or metallurgical operations conducted to an end.

Producer Gases - Obtained by the partial combustion of coal or coke in air. It consists mainly of carbon monoxide and nitrogen, with small proportions of hydrogen, methane, and carbon dixoide.

Pulp - A mixture of ground ore and water capable of flowing as a fluid. Its dilution or consistency is specified either as solid-liquid ratio (by weight) or as a percentage of solids (by weight).

Pulp Density - The dilution or consistenccy of a pulp specified either as solid-liquid or as a percentage of solids both by weight.

Pyrite - Iron disulfide, FeS_2, often containing small amounts of copper, arsenic, nickel, cobalt, gold, selenium.

Pyrometallurgical - Referring to pyrometallurgy involved in winning and refining metals where heat is used, as in roasting and smelting to remove metals from ores. It is the most important and oldest of the extractive processes.

Quench - To cool suddenly (as heated steel) by immersion especially in water or oil.

Raffinate - The solvent-lean, residual feed solution, with one or more constituents having been removed by extraction or ion exchange.

Reductant - A reducing agent, one which readily parts with valance electrons and by becoming oxidized reduces the acceptor of these electrons. Carbon and hydrogen are important chemical reductants.

Reduction - A chemical reaction in which electrons are added to the constitution of the reactant. A reaction which takes place at the cathode in electrolysis.

Refractory - A material of a very high melting point with properties that make it suitable for such uses as furnace linings and in kiln construction. Difficult to treat, usually contianing a second metallic constituent.

Roast - To heat to a point somewhat short of fusing, with or without access to air, so as to expel volatile matter or effect oxidation. In copper metallurgy, applied specifically to the final heating which causes self-reduction to occur by the reaction between the sulfide and the oxide.

Roaster - A device for roasting or a furnace for drying salt cake. A reverberatory furnace or a muffle is used in roasting ore.

Slaked Lime - A hydrated form of lime, as a dry powder, putty or aqueous suspension.

Slurry - Pulp not thick enough to consolidate as a sludge but sufficiently dwatered to flow viscously.

Smelting - The chemical reduction of a metal from its ore by a process usually involving fusion, so that the earthy and other impurities, separating as lighter and more fusible slags can readily be removed from the reduced metal. Thermal processing wherein chemical reactions take place to produce liquid metal from a beneficiated ore.

Smelting Furnace - A blast furnace, reverberatory furnace, or electric furnace in which ore is smelted for the separation of a metal.

Steam Stripping - Separation of a volatile component from a solution through evaporation produced by the steams heat.

Stoichiometric - A chemical compound, or a batch for synthesis, is said to be stoichiometric when the ratio of its constituents is exactly that demanded by the chemical formula.

Stripping - In chemical extraction of minerals, treatment of pregnant solution to remove dissolved values.

Sulfonation Roasting - Roasting in which conditions in furnace allow sulfur in feed to recombine with calcined products to form sulfates.

Surge Tank - In pumping of ore pulps or solutions a relatively small tank which maintains at least a minimum inventory of fluid in the system.

Tails - The inferior, less valuable, or refuse part of an ore remaining after the valuable constituents have been removed.

Thickener-Settler - A vessel or apparatus for reducing the portion of water or solution in a pulp. The pulp settles to the bottom for removal while the liquid is drawn off the top. Usually large, shallow basins with revolving mechanisms to move solids to the discharge.

Top Blown Rotary Converter - A furnace, cylindrical in shape, that rotates continuously about its longitudinal axis. The resulting turbulent bath promotes good mixing of liquids, solids, and the stream of gas directed, through a lance, at the upper surface of the melt.

Underflow Density - The method of describing, usually by weight percent, the ratio of solid to liquid exiting the bottom of a thickener - settler or other concentrating mechanisms.

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